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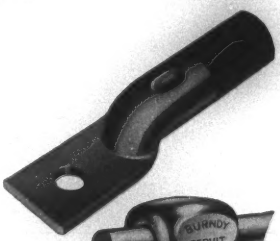

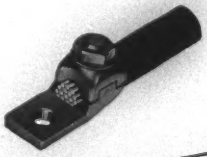

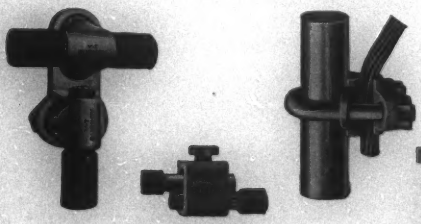

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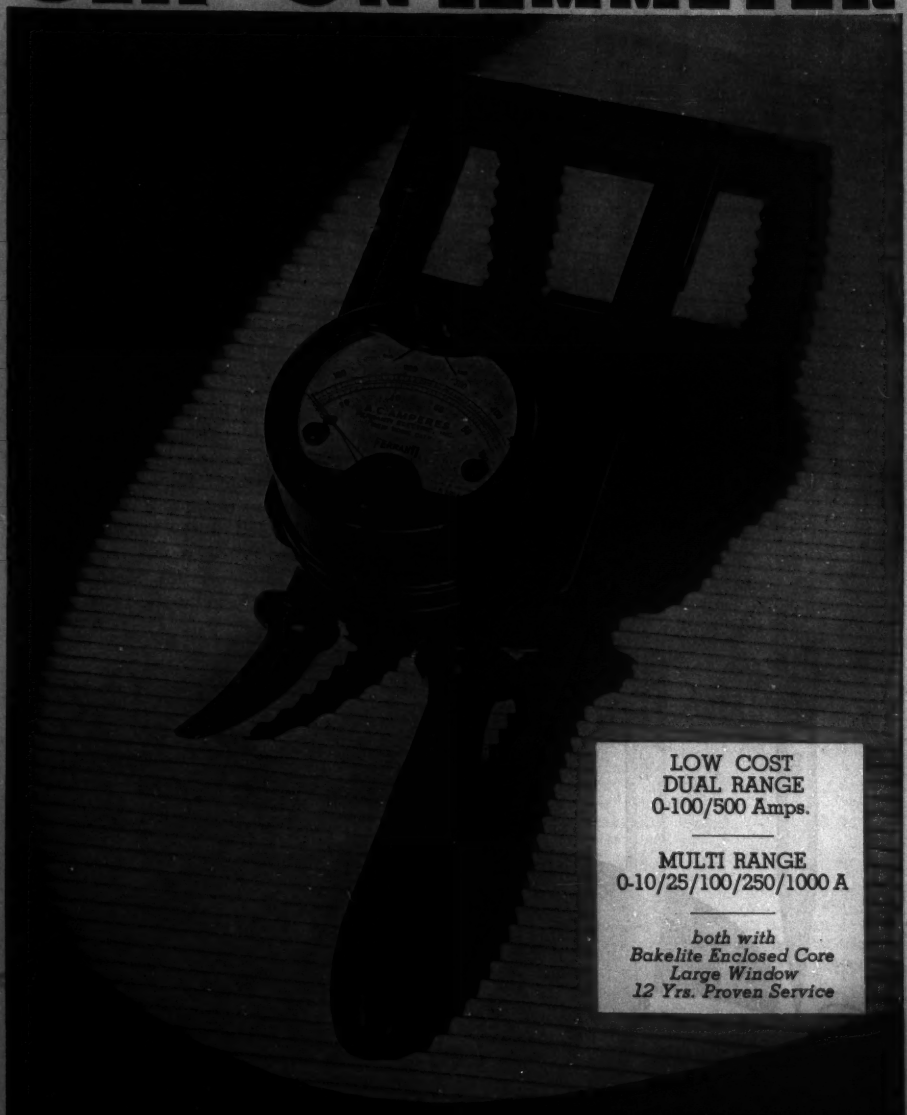

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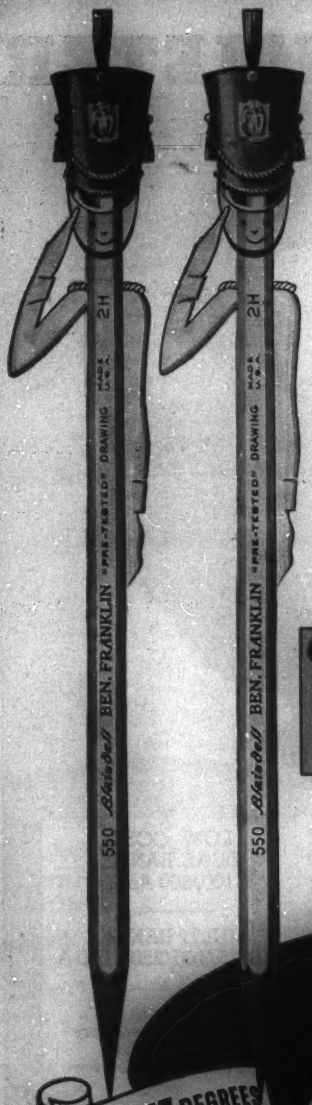
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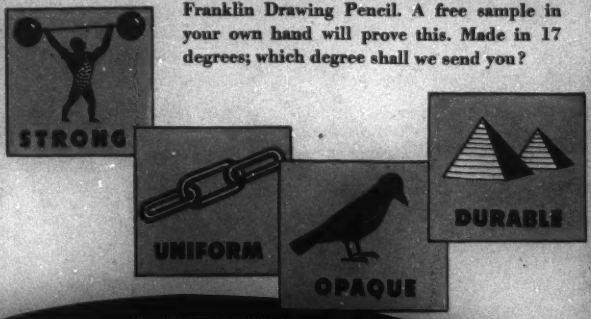

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OKONITE RESEARCH DEVELOPMENT
REPORT NO. 23-Y

August 12, 1944

REPORT AFTER 1 YEAR'S EXPERIENCE ON THE EFFECT OF REPLACING NATURAL RUBBER WITH GR-S(BUNA S) IN OKOLITE INSULATION FOR ELECTRICAL CABLES

We have stated in the past that we are fortunate that the results obtained are so generally satisfactory when Buna S is substituted for natural rubber in Okolite insulation. This is largely because of the fact that natural rubber was a relatively minor ingredient of Okolite and the substitution of Buna S constitutes a smaller change in the compound than in the case of rich rubber compounds. The result is that Okolite S, as we will call Okolite when made with Buna S, is much more like Okolite made with natural rubber and can be expected to be more likely the same in service than in the case of compounds which require greater changes in their composition in order to substitute GR-S or Buna S synthetic rubber for natural rubber. It is obvious that any lack of uniformity in GR-S synthetic rubber will have a greater effect on the properties of an insulation compound in proportion to the amount of GR-S in the compound.

ELECTRICAL STRENGTH: Experience in the manufacture of wires and cables made with Okolite S insulation on a commercial production basis is now approaching one year. The results have been highly satisfactory. The Okolite S insulated conductors are subjected to the same high voltage a.c. and d.c. tests as were used for Okolite made with natural rubber. These high voltage tests are the most severe in use in the wire and cable industry. They help to provide assurance to our customers and to ourselves against weaknesses or defects in the insulation.

INSULATION RESISTANCE: A careful review of our routine test results obtained on all of the Okolite S insulated wires and cables made since January 1, 1944, shows that we can now dependably meet minimum megohm values based on a constant of 10,560 for megohms per 1,000 ft. This is the minimum value that we guaranteed for Okolite made with natural rubber.

WEATHERING: Samples of Okolite S insulated conductors without any coverings over the insulation, have been exposed to the sunshine and weather in our proving ground for the past nine months. The Okolite S insulation is still in excellent condition, its outer surface being practically free from checking, and it is equally as good as the Okolite made with natural rubber. We regard the behavior of Okolite S in this sunlight and weather exposure test as a good indication of stability and long life.

MOISTURE RESISTANCE: Tests were made on cable immersed in water for periods up to one year. We feel that our Okolite S insulation as now manufactured with Buna S is equal in moisture resistance to Okolite manufactured with natural rubber and possibly with further experience this can be still further improved.

The table below shows a comparison of important characteristics of Okolite S versus Okolite made with natural rubber. The results given in this table are as obtained in numerous tests made on the two compounds. It will be observed that there is no important difference in any of the properties covered by the table.

PROPERTIES OF OKOLITE INSULATION
NATURAL RUBBER VS. GR-S

	Okolite (Natural Rubber)	Okolite S (GR-S)
Tensile Strength-p.s.i.	525	525
Elongation-inches	2 to 8	2 to 8
Resistance to Cold	Fair	Fair
Heat	Excellent	Excellent
Ozone	Excellent	Excellent
Oil	Fair	Fair
Sunlight	Good	Good
Flame	Poor	Poor
Moisture	Excellent	Excellent
Dielectric Strength-Volts/Mil	400-500	400-500
Insulation Resistance Constant (1000ft.,60°F)	15,000	14,000
Dielectric Constant (60 Cycle-80 Volts/Mil)	4.2	4.0
Power Factor-Per Cent (60 Cycle-80 Volts/Mil)	3.0	3.0

We can feel assured, as far as can be determined by such limited experience as we have obtained in 1 year of actual production, that Okolite S has all of the excellent properties and high quality of Okolite made with natural rubber.

OKOLOY Corrosion-Resistant Conductor Coating: Another important point in connection with Okolite S insulated wires and cables is the fact that the conductor coating is our standard Okoloy with which there have been many years of satisfactory service experience.

The above report is excerpted from a recent comprehensive report of the Research Laboratory of The Okonite Company, Passaic, N. J., manufacturers of insulated wires and cables.

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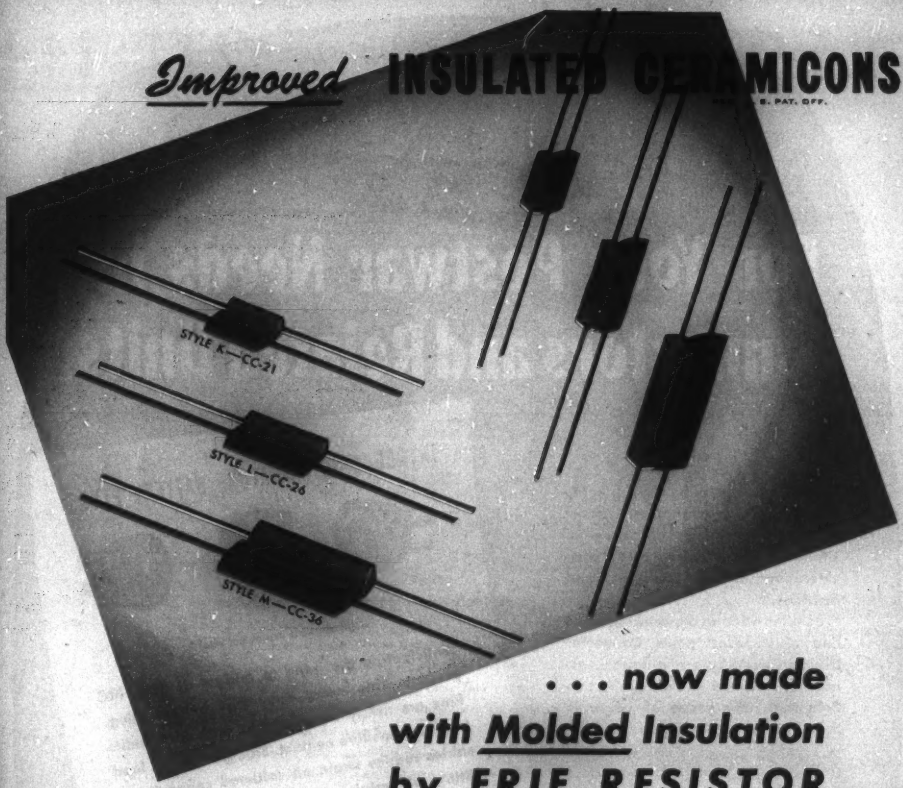

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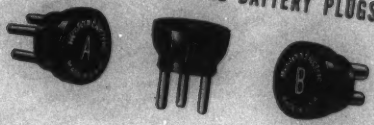

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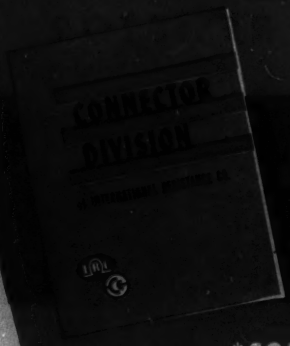

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OCTOBER

1944

The Cover: Boiler-control room of Frank R. Phillips station of the Duquesne Light Company Pittsburgh, Pa. Electrical instrumentation and control contribute toward wartime fuel conservation by maintaining efficient combustion in steam-electric generating stations.

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ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 10 OCTOBER 1944

Gyroscopic Stabilizer for Tank Guns

C. R. HANNA
MEMBER AIEE

L. B. LYNN
ASSOCIATE AIEE

An electrically controlled hydraulic system, gyroscopically governed, is used to stabilize guns mounted in tanks so that gunners may score a high percentage of hits while the vehicles are traveling across rough ground. Development of the system is described herein.

IN 1939 the problem of stabilizing guns in tanks for the condition of traveling over rough terrain was presented by Colonel David J. Crawford, Ordnance Department, United States Army, then a captain at Aberdeen Proving Ground. Colonel Crawford had previously seen certain regulating devices involving the use of gyroscopes and felt that such a combination of equipment would be necessary in the solution of his problem. Consideration was given to this, and it was found that the required speeds and accelerations of the power drive for such a stabilizer were in excess of anything previously attempted. For example, the principal disturbances were at about $1^1/_2$ cycles per second corresponding to the pitching frequency of the tank on its springs, and displacements were such as to cause rates of about 30 degrees per second and accelerations of 300 degrees per second per second.

There were several conditions favorable to the solution of the problem, however:

1. The relatively great inertia of the gun barrel itself which if balanced and left alone would tend to maintain a fixed angle in space.

2. The relatively low trunnion friction would produce only small angular accelerations of the gun as the tank pitched and rolled.

3. The usual practice in gun mounts was to provide fairly close balancing of the mass about the trunnions and so acceleration torques imposed on the gun due to vertical or horizontal movements of the tank would be relatively small.

4. The impulse torque of firing would be small because the trunnion axis and the axis of the barrel intersect within close tolerances.

The conditions of use, however, were rather severe because of the great vibration, wide ranges of temperature, and the presence of dust and moisture.

A further factor of great importance which had to be kept in mind was the need for simplicity and compactness of the stabilizer because of maintenance difficulties and the relatively cramped space in a tank turret.

C. R. Hanna is manager, electromechanical department, and L. B. Lynn is in the research laboratories, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The authors acknowledge the co-operation of officers of the United States Army Ordnance Department and J. H. Ashbaugh, E. R. Wolfert, and J. G. Ritter of the appliance division of the Westinghouse Company, where the device was designed for manufacture.

CHOICE OF SERVOMECHANISM

Devices of the class to be considered all employ power means for stabilizing the gun rather than a large gyroscope capable of resisting directly the disturbing torques. A piloting gyroscope system of small size may readily be used to control the power system in a proper manner to effect stabilization.

It was quickly determined that an electric-motor arrangement was unsuited to the tank stabilization problem because of the extreme accelerations required. In order to obtain high angular accelerations with electric-motor drives, it is necessary to employ very large equipment with small reduction ratios, and the limited space prevented any such choice. Hydraulic servomotors using variable-displacement pumps could not be used because of the high frequencies at which the wobble plate of such pumps would have to be shifted. Hydraulic systems involving two-way slide valves were ruled out because of difficulties due to friction and large movements required for such valves.

The system actually chosen uses two constant-displacement pumps, one for each end of the hydraulic cylinder, with pressure difference for the two pumps controlled by a pair of seated by-pass valves actuated by a teeter-bar armature of an electromagnet system. Figures 1 and 2 show the combination of pump and magnet valve. Three spur gears comprise the double pump having constant delivery. The discharge from each pump normally passes through one of the seated valves. When either valve is partially closed by a differential pull due to the magnet coils, the pressure rises and forces oil into the cylinder supplied by that pump. Oil from the opposite cylinder may discharge readily through the other valve because of its increased opening. The magnet valve is disposed within the sump of the hydraulic system and therefore operates with freedom from friction due to packing. Moreover, the flow from the pumps is available in any proportion immediately upon very small movements of the seated valves and the action is therefore practically instantaneous. The size of the cylinder and the areas of valves and connecting pipes are chosen to give relatively small hydraulic coupling between the tank and the gun so that the added disturbance from this source over and above the trunnion friction and unbalanced acceleration torques previously mentioned is small. The servo system must necessarily develop torques which equal at every instant the combined disturbing torques arising from all coupling members between tank and gun. Great advantage, therefore, arises from the choice of high-pressure low-delivery hydraulic systems. Such choice also contributes to the possibility of designing quick-acting valves because the size of the ports and the magnitude of travel can be kept very small.

GYROSCOPE SYSTEM

The absence of appreciable velocity damping in the hydraulic system chosen made it necessary to incorporate velocity sensing in the piloting device in order to provide adequate regulator damping. The gyroscope unit shown in Figure 3 is attached to the gun recoil cylinder so that it partakes of angular movements of the gun about its trunnions but does not recoil with the barrel. The lower of the two gyroscopes has one degree of freedom about a vertical axis and precesses against spring centering through an angle which is proportional to the angular velocity of the gun about its trunnions.[1,2] This gyroscope is known as an anticipating gyroscope because of its response to angular velocity which always precedes the accumulation of an error in the gun position. It is hydraulically damped by a double-bellows system to prevent resonance of its movement about the vertical precession axis.

The upper gyroscope shown in Figure 3 is a vertical reference gyroscope and was used in all of the early gun stabilizers because Ordnance officers thought an accurate space reference was necessary. It is a slightly pendulous double-gimballed gyroscope co-operating with a single-plane pendulous member mounted on separate bearings which have their axis parallel to the trunnions of the gun. The pendulous member is coupled to the gyroscope through friction shoes and bearing plate in a manner to cause the gyroscope to seek a vertical and to be highly damped in its conical oscillation. Whenever the pendulous member is off vertical, the friction plate of the pendulum presses against one of the shoes mounted on the gyroscope and the resulting precession of the gyroscope about its right-angle axis is accompanied by sliding friction in proportion to the precessional velocity. This method of damping allows complete return of the gyroscope and pendulum to vertical because the friction goes to zero at this point.

The pendulous member carries the electric control device for determining the operation of the magnet valve previously described. Two Silverstat members[3] such as have been used on voltage regulators for a number of years comprise this electric control. They are shown in detail in the schematic circuit diagram of Figure 4. The Micarta spacer or pusher between the Silverstats is carried by the lower or anticipating gyroscope of Figure 3 and moves in a horizontal sense through a displacement proportional to the angular velocity of the gun as previously described. The Silverstat leaves being carried by the pendulum undergo a horizontal displacement in proportion to angular movement of the back plate of the gyroscope unit and this is, of course, equal to the error angle of the gun from its desired position. Thus, the Silverstat members are actuated in proportion to angular velocity and angular displacement of the gun by means of the two gyroscopes.

From the schematic circuit in Figure 4 it is seen that each Silverstat controls one of the electromagnets of the valve by short-circuiting successively the steps of two tapped resistors. These are graded in a manner to give magnet forces which are in proportion to displacements at the Silverstats. The over-all electro-hydraulic system, therefore, provides corrective torques at the gun which are in proportion to angular velocity and angular displacement of the gun from a fixed position with the result that a rapid correction during disturbances is effected.

Arrangement is made to employ the power from the hydraulic system in aiming the gun. Figure 5 shows the gyroscope unit H so attached to the gun that it may be rotated by means of a handwheel, flexible shaft D, and worm gear F to assume various angular relations with the gun. As the handwheel is rotated, the gyroscope unit attempts to depart from vertical, but the resulting deflection of Silverstat control members produced by the co-operative action of the two gyroscopes causes the gun to move in the direction to permit the gyroscope unit to stay vertical. Thus, power aiming is obtained in this simple manner through the same controls that cause stabilization.

Figure 2. Oil pump with cover removed

A further auxiliary control is needed to prevent violent disturbances which would otherwise be caused by the large gravity unbalance during recoil of the gun barrel. For this purpose there is a Microswitch which closes when the gun recoils and this supplies current to an auxiliary magnet coil of the valve in a manner to provide supporting pressure for the breech heaviness during recoil. The Microswitch and auxiliary magnet coil are shown in Figure 4. The adjustment for this recoil control need be only approximate because the gyroscope unit through its Silverstat control of the other magnet coils can compensate for discrepancies.

PERFORMANCE

The original request of the Ordnance Department was that disturbances of $\pm 2^1/_2$ degrees at $1^1/_2$ cycles per second for the tank should be reduced to $\pm^1/_2$ degree error at the gun. It was further requested that the vertical gyroscope period be such as to return following a disturbance in less than two seconds. It was realized, however, that short-period vertical gyroscopes must employ large pendulous members which may be too responsive to lateral accelerations for good over-all performance. It therefore was suggested to the Ordnance Department that this part of the specification be altered to read that the return of the gyroscope to vertical following any disturbance be as rapid as possible, consistent with permissible lateral acceleration errors.

The stabilizer as developed exceeded the accuracy specification by about three to one, that is, $\pm 2^1/_2$ degrees disturbance at $1^1/_2$ cycles per second resulted in error at the gun of less than $\pm^1/_8$ degree instead of $^1/_4$ degree as

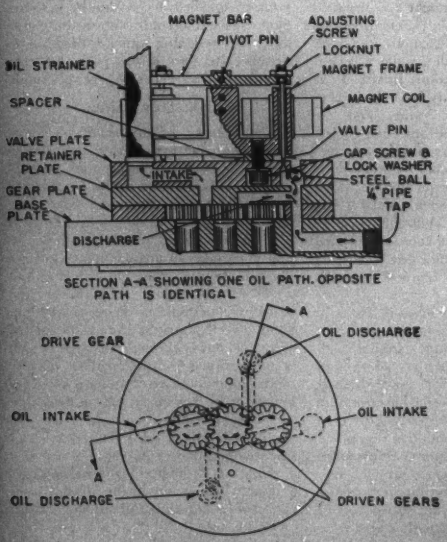

Figure 1. Schematic view of oil pump showing magnet valves and oil passages

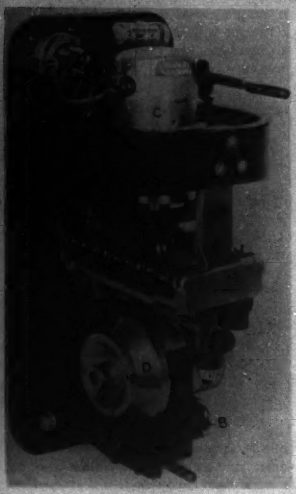

Figure 3. Double-gyroscope control with cover removed

A—Silverstat control *C—Motor and flywheel*
B—Bellows *D—Motor and flywheel*

specified. The acceleration response, however, presented some difficulty because of rapid starting and stopping of the tank. With the early double-gyroscope equipment, even with fairly long periods of 20 seconds or more for the vertical gyroscope, the response to lateral accelerations was too pronounced. It was necessary, therefore, that the gunner fire only during periods when the tank was running at fairly uniform velocity.

Under such conditions excellent stabilizer performance was secured. It was found possible to obtain better than 70 per cent hits over a variable range of 1,200 yards to 300 yards from target at speeds of approximately 15 miles per hour over cross-country terrain. Under similar conditions without the stabilizer, fewer than one per cent hits were possible even with experienced gunners. A further collateral advantage was that approximately three times as many sighted shots could be made in a given time with stabilization.

SIMPLER VELOCITY-TYPE STABILIZER

During the early development work on the gun stabilizer, as for example, with the equipment shown in Figure 6, experiments were made with the upper or vertical-reference gyroscope locked to the back plate so that the resulting control of the Silverstat members was due only to the angular-velocity response of the lower gyroscope. It was found that the electrical sensitivity of the system could be increased without hunting because of the greater ease with which velocity systems are damped as contrasted to those of the position type. Although such a system would allow the gun to drift very slowly because of the absence of positioning sense, it was found to exhibit very large resistance to angular velocities which should be sufficient for stabilization purposes. Nothing further was done at this stage of the development because of the feeling on the part of the Ordnance officers that an accurate gyroscope vertical reference was necessary.

After several thousand of the dual-gyroscope units were built and in service, the Ordnance Department agreed that satisfactory stabilization could be obtained using only the velocity-responsive gyroscope. They also found that with the vertical gyroscope blocked out they could obtain some degree of vertical reference when the complete gyroscope unit was rotated to a position 180 degrees from its normal operating position. Later it was found that the gravity response was caused by an offside unbalanced weight of the velocity gyroscope due to the angle member which supports the pusher for the Silverstats. When the gyroscope is in the upside-down position, this weight causes a slight deflection of the Silverstats in the proper sense whenever the gyroscope unit is tilted from vertical, and a gradual return to vertical occurs.

Aside from the advantages of simplicity in omitting one of the two gyroscope members, it was found that response to lateral accelerations was greatly reduced because of the small value of this offside weight.

The lack of accuracy in the vertical reference of the simplified gyroscope unit was at this stage felt to be relatively unimportant because the gunner continually aims the gun by handwheel rotation of gyroscope unit relative to gun and any very slow drifting caused by lack of an accurate vertical reference is readily compensated without appreciable further effort on his part.

Accordingly, all stabilizer equipment currently built for tank guns is of the monogyroscope type shown in Figure 7. This is seen to be merely the anticipating gyroscope of the early equipment turned

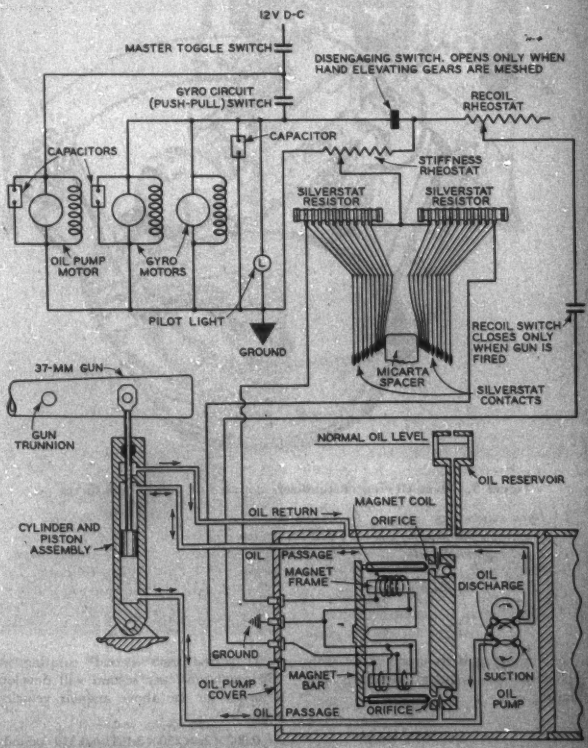

Figure 4. Schematic circuit of double-gyroscope system

upside down with Silverstats integral with the back plate.

THEORY OF THE POSITION-TYPE STABILIZER

Let it be assumed that a gun having inertia $I=280$ pound feet second^2 is to be stabilized to an accuracy of $\pm 1/20$ degree for a disturbing torque of ± 100 pound feet. The required regulator stiffness

$$S=\frac{100}{0.05}=2{,}000 \text{ pound-feet per degree}$$
$$=2{,}000\times 57.3=114{,}600 \text{ pound-feet per radian}$$

In order to damp the regulator system, a response to angular velocity is provided by the anticipating gyroscope. Let this be of such a value as would produce critical damping if its action were truly responsive to angular velocity. The damping

$$r=2\sqrt{IS}=2\sqrt{280\times 114{,}600}$$
$$=11{,}300 \text{ pound-feet per radian per second}$$

The ratio r/S has the dimension of time and will be called the anticipation time.

$$T_a=\frac{r}{S}=\frac{11{,}300}{114{,}600}=0.0986 \text{ second}$$

In the regulator design this value is obtained by choosing gyroscope momentum and restraining-spring stiffness properly. For example, if the full range of Silverstat displacement is obtained for $\theta=0.01$ radian angular displacement error of the gun, then the anticipating gyroscope must give full Silverstat displacement for an angular velocity

$$\Omega=\frac{0.01}{T_a}=\frac{0.01}{0.0986}=0.1015 \text{ radian per second}$$

A gyroscope having spin inertia $I_s=0.002$ pound inch second^2 rotating at 250 revolutions per second will develop a torque for the above angular velocity given by

$$L=0.002\times 2\pi\times 250\times 0.1015=0.319 \text{ pound-inch}$$

If the precession angle of the anticipating gyroscope is 0.02 radian for full Silverstat displacement, the restraining spring stiffness must be

$$S_p=\frac{0.319}{0.02}=15.95 \text{ pound-inches per radian}$$

Because of the inertia of such a gyroscope about its precession axis, the deflections of S_p and therefore the displacements of the control Silverstats will not be in exact phase with the angular velocity of the gun. Also, the precession inertia and restraining spring constitute a resonant system which must be damped. For a critically damped precession movement, the velocity response of the system will be altered by the operational factor

$$\frac{1}{1+\frac{r_p}{S_p}p+\frac{I_p}{S_p}p^2}=\frac{1}{\left(1+\sqrt{\frac{I_p}{S_p}}p\right)^2}$$

That is, if the damping r_p due to the bellows is made equal to the critical value, the quadratic expression can be factored into two equal linear factors. For the case at hand $I_p=0.006$ or about three times the spin inertia and

$$\sqrt{\frac{I_p}{S_p}}=\sqrt{\frac{0.006}{15.95}}=0.0194 \text{ second}$$

The differential equation for the position-type system, neglecting delays in the hydraulic system, is

$$-I\dot{p}^2\theta=S\theta+\frac{r\dot{p}\theta}{\left(1+\sqrt{\frac{I_p}{S_p}}p\right)^2} \qquad (1)$$

Substituting numerical values:

$$-280\,p^2\theta=114{,}000\theta+\frac{11{,}300\,p\theta}{(1+0.0194\,p)^2}$$

$$0.1054\,p^4+10.86\,p^3+323\,p^2+15{,}725\,p+114{,}000=0$$

Clearing:

$$p^4+103\,p^3+3{,}065\,p^2+149{,}250\,p+1{,}081{,}500=0 \qquad (2)$$

Factoring:

$$(p+8.3)(p+85.9)(p^2+8.84p+1{,}518)=0 \qquad (3)$$
$$p=-8.3$$
$$p=-85.9$$
$$p=-4.42\pm j38.7$$

The solution of the differential equation is therefore

$$\theta=Ae^{-8.3t}+Be^{-85.9t}+e^{-4.42t}(C\cos 38.7t+D\sin 38.7t) \qquad (4)$$

The first two terms are nonoscillatory and die out very quickly. The oscillatory terms have frequency

$$f=\frac{38.7}{2\pi}=6.16 \text{ cycles per second}$$

The rate of decay per cycle is given by

$$1-e^{-\frac{4.42}{6.16}}=0.51$$

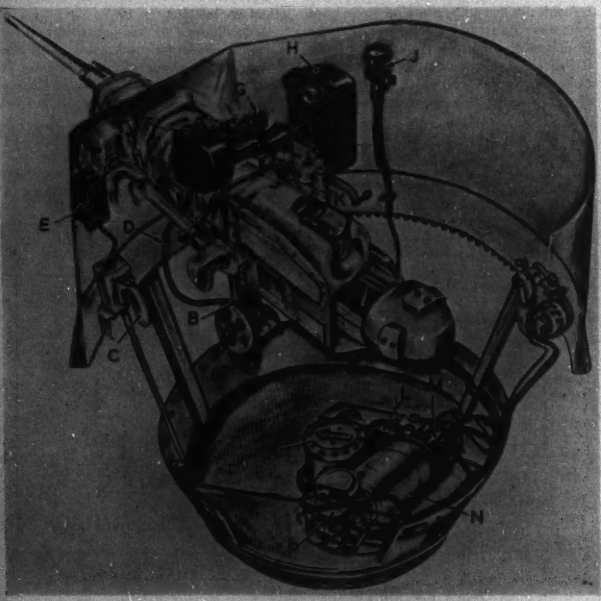

Figure 5. Over-all view of stabilizer mounted on gun in tank turret

A—Turret collector ring
B—Disengaging switch
C—Traversing-control handle
D—Flexible shaft
E—Control box
F—Gear box and mounting bracket
G—Cylinder and piston
H—Gyroscope control
J—Reservoir
K—Recoil switch
L—Master switch
M—Oil pump
N—Electric motor
P—Hydraulic traverse pump

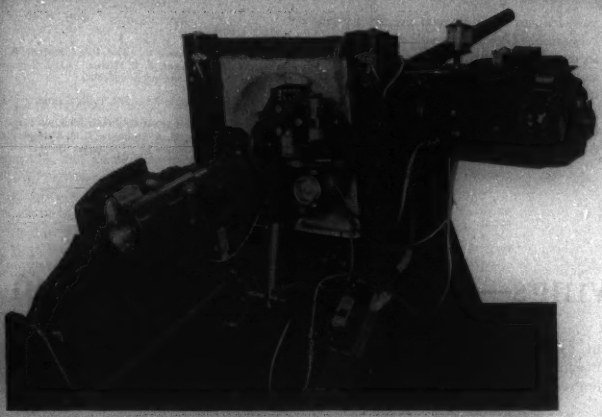

Figure 6. Double-gyroscope control mounted on gun

The damping is less than the critical value because of the imperfections of the anticipating gyroscope in giving true velocity response. If higher damping is desired, it is possible in actual installations to obtain it by reducing the over-all regulator sensitivity by the stiffness control indicated in Figure 4. This reduces both r and s in the same proportion in equation 1. Suppose they are both halved. Then

$$-280\,p^3 = 57{,}000 + \frac{5{,}650\,p}{(1+0.0194\,p)^2} \qquad (5)$$

$$0.1054\,p^4 + 10.86\,p^3 + 301.5\,p^2 + 7{,}862.5\,p + 57{,}000 = 0$$

$$p^4 + 103\,p^3 + 2{,}865\,p^2 + 74{,}625\,p + 540{,}750 = 0 \qquad (6)$$

$$(p+9.7)(p+77.3)(p^2+16\,p+720) = 0 \qquad (7)$$

$$p = -9.7$$
$$p = -77.3$$
$$p = -8 \pm j\,25.6$$

The solution of this is

$$\theta = Ae^{-9.7t} + Be^{-77.3t} + e^{-8t}\,(C\cos 25.6t + D\sin 25.6t) \qquad (8)$$

The oscillation frequency is

$$f = \frac{25.6}{2\pi} = 4.08 \text{ cycles per second}$$

The rate of decay per cycle is

$$1 - e^{-\frac{8}{4.08}} = 0.86$$

which represents very high damping.

The second choice of regulation stiffness will still hold the error to $\pm 1/10$ degree for the assumed disturbance of 100 pound-feet.

THEORY OF THE VELOCITY-TYPE STABILIZER

In the single-gyroscope type of stabilizer the restoring stiffness s_p of the gyroscope about its precession axis was reduced to about 40 per cent of that in the anticipating gyroscope of the two-gyroscope type. This was done to increase the response to angular velocity. The time delays (that is, $\sqrt{I_g/s_p}$) for the precessional movement of the gyroscope were thus increased from 0.0194 second to 0.03 second, but the greater ease of obtaining freedom from hunting for velocity regulators over position regulators permitted the larger delays.

If Ω represents angular velocity deviations from zero velocity for the gun, the equation of motion is

$$-280\,p\Omega = \frac{r\Omega}{(1+0.03\,p)^2} \qquad (9)$$

$$0.252\,p^3 + 16.8\,p^2 + 280\,p + r = 0$$

For stability Routh's criteria states that the product of the coefficients of the two middle terms must exceed the product of the coefficients of the two outside terms or

$$16.8 \times 280 > 0.252\,r$$
$$r < 18{,}670$$

Try

$r = 6{,}000$ pound-feet per radian per second:

$$0.252\,p^3 + 16.8\,p^2 + 280\,p + 6{,}000 = 0$$
$$p^3 + 66.7\,p^2 + 1110\,p + 23{,}800 = 0 \qquad (10)$$

$$(p+54.35)(p^2+12.35\,p+439) = 0 \qquad (11)$$
$$p = -54.35$$
$$p = -6.175 \pm j\,20$$

The solution of the equation is therefore

$$\Omega = Ae^{-54.35t} + e^{-6.175t}\,(B\cos 20t + C\sin 20t) \qquad (12)$$

The frequency of free vibrations for the system is

$$= \frac{20}{2\pi} = 3.18 \text{ cycles per second}$$

and the decay rate per cycle is

$$1 - e^{-\frac{6.175}{3.18}} = 0.855$$

This represents very high damping.

An evaluation of the accuracy of this stabilizer may be obtained by assuming the 100 pound feet disturbing torque as in the previous calculations and letting it be sinusoidal in character. If the frequency is say $1^1/_2$ cycles per second, the damping $r = 6{,}000$ pound feet per radian per second will develop 100 pound feet torque for an error given by

$$\Omega = 2\pi \times 1^1/_2\,\theta = \frac{100}{6{,}000}$$
$$\theta = 0.00177 \text{ radian}$$
$$= 0.1013 \text{ degree}$$

Comparison of the accuracies for the velocity- and the position-type regulator systems here chosen shows them to be practically identical for the $1^1/_2$-cycle disturbance. The rates of decay are also the same. This theoretical result has been borne out in practice by mechanical oscillator tests. The advantage is of course in favor of the single gyroscope or velocity-type stabilizer because of its greater simplicity and its greater freedom from acceleration errors.

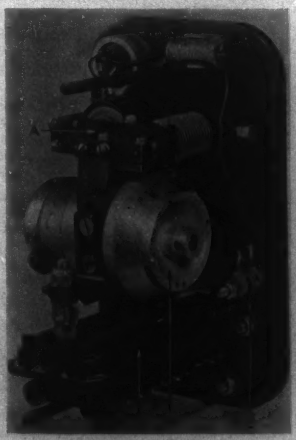

Figure 7. Monogyroscope control with cover removed

A—Bellows
B—Motor and flywheel
C—Resistor
D—Silverstat control

PRACTICAL APPLICATION

The early development work and the evolution during use have lead to a very simple but effective stabilizer for tank guns. Research starting late in 1939 was well toward completion by the fall of

1940. Mass production began early in 1941. All but the first few United States tanks and many of the tanks of the Allies have been equipped with this device.

The wartime development of stabilizers has pointed the way to applications which will be made when peace comes. In particular, the riding comfort of all classes of vehicles can be improved greatly by stabilization. Gyroscopes will not be needed in general, but rapid servo systems, such as the one employed in the gun stabilizer, under control of the appropriate pilot device or "brain" will cause the vehicle body to float when traveling over the roughest road.

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1. Recent Developments in Speed Regulation, C. R. Hanna, K. A. Oplinger, & J. Mikina. AIEE *Transactions*, volume 59, 1940, pages 692–700.

2. United States patent 2,162,482, C. R. Hanna.

3. Recent Developments in Generator Voltage Regulation, C. R. Hanna, K. A. Oplinger, C. E. Valentine. AIEE *Transactions*, volume 58 ,1939, pages 838–44.

Trimetric Drawings—An Aid to Production

Three-dimensional drawings of a type known as trimetric drawings may be produced in less time with the aid of innovations developed by W. G. Wilkinson and H. C. Bartholomew of The Glenn L. Martin Company, Baltimore, Md., and thus become more readily available for production illustration.

By presenting three dimensions with a minimum of distortion, a clearer picture of the assembly of parts is presented than can be done by orthographic projections. A new machine called an Axonograph photographically translates a conventional orthographic drawing into a scale representation of one face of a trimetric projection, and the other two faces are filled in by a draftsman. By adjusting the machine, the print may be produced in any one of the three planes—plan, face, or side—and the scale varied as required New drawing instruments were developed for use in the process (Figure 1).

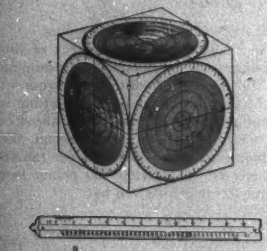

Figure 1. Four new trimetric drawing instruments

Top—Ellipse underlay for drawing ellipses greater than one inch in diameter on the three principal planes, and for scaling nontrimetric lines

Center—Trimetric scale for measurements on three axes

Lower left—Ellipse template for drawing ellipses up to one inch in diameter on the three principal planes

Lower right—Trimetric protractor for angular measurements on the three principal planes

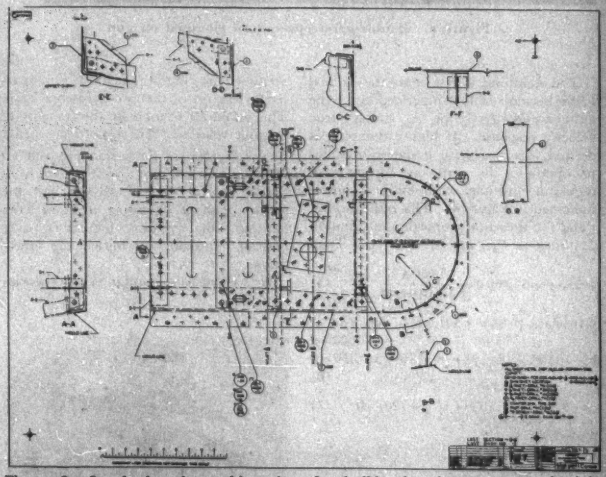

Figure 2. Standard orthographic print of a bulkhead as it appears on the loft template

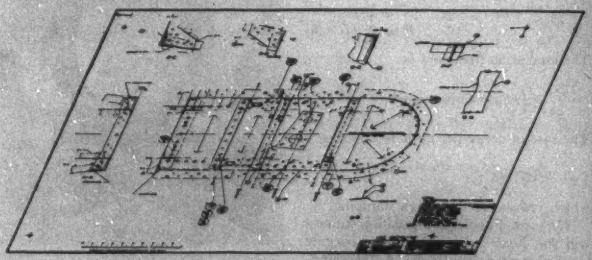

Figure 3. Axonometric print of bulkhead as delivered by the Axonograph

Figure 4. Trimetric print of bulkhead traced from the Axonometric print with added dimensions filled in by hand

Experience With a Heat-Pump System

THE HEAT PUMP, which provides a means for absorbing heat at one level and discharging it at another and higher level, is best known by its application to refrigeration. However, the cycle may be operated so that the principal interest is heating instead of cooling, and recently much notice has been given to the application of heat pumps in buildings for heating in winter and cooling in summer.

Four years' operating experience with a heat-pump heating system in the administration building of The United Illuminating Company in New Haven, Conn., has shown that such a system is satisfactory in a climate where degree days, on a 65-degree Fahrenheit base, have varied from 5,234 to 5,948 during the past four years and subzero temperatures are rare. Adequate heat is produced, the distribution of heat is satisfactory, and costs compare favorably with the costs of other methods of heating provided proper credit is given for the dual use of the system for heating and cooling.

Three factors make the system feasible for this building:

1. A large portion (40 per cent by volume) of the building is equipped for summer air conditioning.
2. An adequate water supply is available from shallow wells below the basement level.
3. Low-cost electric power is available.

The system consists of 40-horsepower hermetically sealed refrigeration units which absorb heat in their evaporators and give it up in their condensers, together with the heat of compression which is furnished by the motors. Driven wells in the basement of the building tap a supply of water which is at an almost constant temperature of 57 to 58 degrees Fahrenheit throughout the year and is used to supply heat in winter and absorb heat in summer. Piping distributes either heated or chilled water throughout the building. To heat the building the operation of up to five units is required and the temperature of the well water is lowered to 51 degrees while the temperature of the hot water being circulated is raised to 130 degrees. Up to three units are required for cooling and dehumidification in summer. During about 35 days of the year, sufficient cooling can be obtained from the well water without operating any units. A simplified flow diagram of the system is shown in Figure 1. Table I summarizes estimates of heating costs using other fuels for the 1942–43 season. Comparative annual fuel costs, with electricity at one cent per kilowatt-hour, are:

Heat pump	$3,950
Anthracite coal	2,410
Bituminous coal	1,790
Number 6 fuel oil	1,660

Against the higher cost of electricity should be credited the following benefits:

1. Absolute cleanliness.
2. No fuel-storage space required.
3. No chimney necessary.
4. Reliable supply of fuel.
5. Excellent working conditions for operators.
6. Probable lower maintenance costs.

Detailed figures on consumption and cost of electricity are given in Tables II and III.

Table I. Comparative Fuel Requirements

	Assumptions For Fuel-Burning System			
	Efficiency, Per Cent	Heat Value, Btu	Cost of Fuel Delivered to Building	Quantity Required
Anthracite coal	67	11,500 per lb	$9.50 per ton	254 tons
Bituminous coal	65	13,500 per lb	8.00 per ton	224 tons
Number 6 fuel oil	70	150,000 per gal	1.87 per bbl	885 bbl

Table II. Consumption of Electricity in Kilowatt-Hours

	1941		1942		1943	
	Heating	Cooling	Heating	Cooling	Heating	Cooling
January	99,400		95,100		77,700	
February	80,300		91,000		58,900	
March	84,000		63,400		62,900	
April	16,900		26,000		44,500	
May		8,300		8,800		12,500
June		24,800		25,700		29,600
July		32,900		37,300		29,600
August		28,800		27,600		26,800
September		18,100		15,500		12,500
October	4,900		6,800	3,900	16,300	8,200
November	37,100		54,300		57,000	
December	72,100		89,900		84,300	
	394,700	112,900	426,500	118,800	401,600	119,200
Degree days	5,398		5,605		5,897	
Kw-hrs. per degree day	73.1		76.0		68.1	

Table III. Operating Costs of Heat-Pump System

	Kilowatt-Hours	Cost Of Electricity At One Cent Per Kwhr	Operating Labor	Maintenance*	Total
Heating season, 1941–42	389,600	$3,896.00	$2,539.50	$ 704.79	$ 7,140.29
Cooling season, 1942	118,800	1,188.00	2,416.55	214.70	3,819.25
	508,400	$5,084.00	$4,956.05	$ 919.49	$10,959.54
Heating season, 1942–43	395,000	$3,950.00	$2,896.55	$ 856.90	$ 7,703.45
Cooling season, 1943	119,200	1,192.00	2,899.16	258.56	4,349.72
	514,200	$5,142.00	$5,795.71	$1,115.46	$12,053.17

* Prorated on basis of kilowatt-hours.

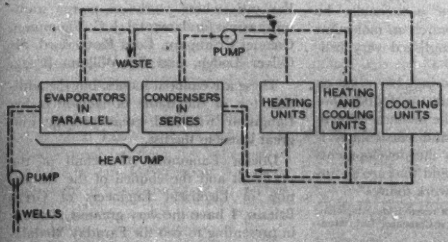

Figure 1. Simplified flow diagram of heat-pump system

Dashed lines—Heating cycle

Dotted lines—Cooling cycle

REFERENCE

1. Heating by Reversed Refrigeration, Regis D. Heitchue. *Electrical Engineering*, volume 61, November 1942, pages 556–60.

Abstracted from a conference paper "Reverse Refrigeration Applied to a New Haven Office Building" by E. Haviland Walton and Charles A. Williams (M'40) presented at the AIEE summer technical meeting, St. Louis, Mo., June 26–30, 1944.

Irving Langmuir—Faraday Medalist

"For his conspicuous contributions to electrical science" Irving Langmuir was awarded the Faraday Medal of the Institution of Electrical Engineers of Great Britain for 1943. The presentation was made at the recent AIEE summer technical meeting.

THE FARADAY MEDAL of the Institution of Electrical Engineers, Great Britain, awarded to Irving Langmuir for 1943, was presented at the AIEE annual meeting, June 26, 1944, during the Institute's summer technical meeting in St. Louis, Mo. The presentation was made by A. P. M. Fleming (F '34), local honorary secretary of AIEE for England since 1929, and past president of IEE. Doctor Fleming himself received the Faraday Medal in 1941. The award was conferred by the council of IEE at its meeting, February 3, 1944.

Twenty-second recipient of the award, Doctor Langmuir, associate director of research, General Electric Company, Schenectady, N. Y., is the fourth American to receive it, the others being AIEE Past Presidents Elihu Thomson and F. B. Jewett, and W. D. Coolidge (M '34). Eleven of the 22 recipients have been AIEE members.

President Funk read the statement for dispatch to the AIEE from the Institution of Electrical Engineers of Great Britain, as follows:

"At their meeting on the third of February, 1944, the council of the Institution unanimously resolved that the 22d award of the Faraday Medal be made to Doctor Irving Langmuir for his conspicuous contributions to electrical science. This award was announced to the members of the Institution at their ordinary meeting on the same day (third of February), the President's statement, a copy of which is attached, being received with acclamation.

"It will be seen from the conditions of award (also attached) that normally the Medal is struck in bronze. This metal was chosen rather than gold, because it was particularly desired that there should be no suggestion of any intrinsic value in the medal itself, but rather that it should owe its value, first to the fact that it was instituted to commemorate the foundation of the Institution, and secondly that it is offered for worldwide services to electrical science and engineering. This year the exigencies of war have required that the Medal should be struck in silver, which was also the case for last year's award, the use of bronze being precluded under emergency regulations controlling the supply of this metal.

"A list of previous recipients of the Medal is given on the attached copy of the conditions of award."

The essential substance of the presentation address delivered by Doctor Fleming and of the speech of acceptance made by Doctor Langmuir is given in the following articles.

Irving Langmuir (left) receives the Faraday Medal from A. P. M. Fleming (F'34)

Irving Langmuir—Pioneer in Research

A. P. M. FLEMING
FELLOW AIEE

The Faraday Medal is awarded not more frequently than once a year, for conspicuous engineering or industrial achievement in electrical engineering, or for a notable service in connection with the development and advancement of electrical science and engineering.

The selection of the Faraday Medalist is done in the first instance in the Institution of Electrical Engineers by a committee of past presidents. They put forward a name for the approval of the council. The council, if it approves, announces that name at a full and open meeting of the Institution.

On this occasion, those of us who were concerned with the selection committee had no difficulty in agreeing on the name of the award. The council accepted that recommendation unanimously, and the enthusiasm in that commission with which the name was received when announced at the open meeting of the members of the Institution left us in no doubt as to the wisdom or the popularity of their choice.

To an American audience it would be absurd for anyone to try to tell of Doctor Langmuir's achievements. They have covered such a wide range. He has been interested in chemistry, in physical chemistry, in physics, metallurgy, electrical engineering, and then occasionally he throws his brilliant research on molecular layers which he accomplished very brilliantly a few years ago.

In electrical engineering, his work on vacuum technique laid the foundations probably of much of the modern work in electrical techniques, and particularly is adding enormously to the developments that have taken place and that are so important in thermionic work today.

A. P. M. Fleming is director of research and education, Metropolitan-Vickers Electrical Company, Ltd., Manchester, England.

He developed the high-vacuum valve. He worked on thyratrons, and his work on the gas-filled lamp, of course, is everywhere known. His activities were always fundamental. They laid the basis on which scores and scores of engineers and others could build. He blazed a trail which inspired vast numbers of researchers to follow in development, and it can be said truly that his work has been of benefit to almost all mankind.

His work is well known, of course, in the United States and overseas. Two honors that were bestowed on him from abroad are the Nobel Prize from Sweden and the Fellowship of the Royal Society in London.

The Faraday Medal is the most coveted distinction that the Institution of Electrical Engineers has to bestow. It is awarded without reference to nationality, to place of residence, country of residence, or to membership in the Institution.

On three previous occasions it has come to the United States and about three years ago Professor Kapitsa, the great Russian physicist, received the Faraday Medal.

There have been many well-known Faraday Medalists: Oliver Heaviside, Sir Charles Parsons of turbine fame, Doctor Farranti, whose work on power transmission was fundamental, J. G. Thompson, Colonel Crumpton, Lord Rutherford, Sir Oliver Lodge, and Sir William Bragg.

These are eminent names, but the addition too of the name of Doctor Irving Langmuir will add great prestige and great luster to the list.

Doctor Langmuir, on behalf of the president and the council of the Institution of Electrical Engineers of Great Britain, I have the very greatest pleasure in presenting to you the Faraday Medal.

Incentives for Science

IRVING LANGMUIR

It is with a deep feeling of appreciation for the honor conferred on me by the Institution of Electrical Engineers of Great Britain that I accept this Faraday Medal. Especially at this time, when America and England are co-operating so closely, I would like to dwell on the significance of this award.

The mutual dependence of England and America in fields of science has long been recognized by scientists. Think of the Battle of Britain in 1940 and what would have happened if England had folded up the way France did. We now know how difficult is the crossing of the English Channel with an invasion army, but what would have been our chances if England had been overrun by Germans? How could we ever have reached Germany or the occupied territories by an invasion directly across the Atlantic? Our success in our contribution to the war has certainly been dependent on England. Yet in equal degree England depends on America. England, single-handed, could not have beaten Germany. The aid that we have given, with our air force supporting the Royal Air Force, and now with the armies in Italy and in France, is a good example of how countries can be mutually dependent and accomplish things together that would be impossible for either one alone.

Britain, United States, and the Soviet Union recognize that they are dependent on science in the carrying on of this war. Every man in the field knows that, every man who flies an airplane; anyone who sinks a German submarine knows what part engineering and science has played in our success.

This medal is a useful example of the recognition of the importance of science. An award such as this should not be regarded as a reward for past accomplishments, but rather as an incentive for new work. This matter of incentive is something that one needs very seriously to consider.

England is offering incentives to scientists, and the spirit of the people is such they will continue to encourage science after the war. Russia also certainly shows every indication of doing the same thing. Even before the war the Russian government was stimulating research to a tremendous degree and much of the Russian armies' success rests on that foundation.

In the United States, although the man on the street and many men in our Armed Forces often know and recognize what scientific work has done, we have had on the part of our Government for many years more or less of an attack on science.

Irving Langmuir is associate director of research, General Electric Company, Schenectady, N. Y.

We first heard that science was responsible for technological unemployment. It was suggested by some that we should have a scientific holiday. Just think now what it would have meant if we had really taken a scientific holiday. Too often now we find that science and industry, especially big industry, is held up as a whipping boy for the evils that arise from other sources, very much as in Germany the Jews have been accused of responsibility for all difficulties that were felt by the people of Germany.

The greatest merit of the capitalistic system, such as we have had in the past, has been its emphasis on incentive. It gave incentive to do big things. We should remember that America got its present leadership in industry and in science under the capitalistic system. This system has had certain disadvantages. There was no question but that it needed corrective measures. It did not avoid serious depressions. There are many things it failed to do. However, we should recognize the useful features of the capitalistic system and plan to retain them even though we make modifications to avoid future difficulties.

I would like to give a couple of examples which come to my mind of the danger that lies ahead in not only failing to provide incentives, but actually penalizing efficiency; those are the things that we must think about and fight against.

During the war the war itself is our incentive; we do not often need any artificial methods to stimulate the scientific and industrial activity. It is not often necessary to pay higher wages or profits to get people to work or fight to win the war. So I have no objection whatever, I believe none of us have, to high taxation, surtaxes, excess profits taxes, and bond drives to help win the war. But, if these are thought of as permanent arrangements, we are in for trouble. We do not want to lag behind Russia and England, but I am afraid there is danger of it if we do not do something to maintain the incentive to do new things which has been so strong in America in the past.

The Kilgore Bill (*S* 702, February 11, 1943) has not passed and probably never will, but it has received sanction from high Government officials. Although it has failed, it is the kind of thing that comes up again and again. Just let me mention a couple of provisions of the Kilgore Bill to show you what I mean.

This bill would permit the Government to support or contribute to research in an industrial laboratory. Industry has to accept this aid if the government so elects. Another clause in the bill says that whenever the Government makes any contribution towards the expense of any problem, which leads to a patent, the patent can be taken over by the government at cost. Thus if the patent is successful the industry derives no benefit from the work done. If, however, it is unsuccessful, nobody helps pay the losses.

Ordinarily a patent can thus be taken over at cost, but there is a significant exception: in the case where the patent is taken out by an individual not connected with an organized laboratory, the Government can give him a reward and pay him more than the cost. In other words, if two people co-operate to increase their efficiency they lose their chance to recover anything more than the cost. Here is an incentive to do things inefficiently; the Government does not want co-operation. Fortunately, the bill has not passed. Perhaps that is one of the reasons. But, is it not amazing that a bill of this kind should be seriously considered?

The other example is more serious for it was involved in a decision of the United States Court of Appeals. This decision, in which a patent owned by a large corporation was declared invalid, contained the argument by the judge that, when a patent is granted to an employee of a large industrial laboratory, the validity of the patent may be questioned, because the efficient organization of the laboratory may have so aided the inventer that the invention becomes the work "of an entire group, not the achievement of an individual." To grant a patent under such circumstances would be "to reward capital investments and to create monopolies for corporate organizers instead of men of inventive genius." The effectiveness of corporate research laboratories is illustrated by the case of the needle in the haystack: "Under a disorganized system of invention a hundred men would hunt

The Roster of Faraday Medalists

1922	Oliver Heaviside*
1923	Sir Charles A. Parsons
1924	S. Z. de Ferranti*
1925	Sir J. J. Thomson
1926	Colonel R. E. B. Crompton
1927	Elihu Thomson*
1928	Sir J. A. Fleming
1929	Guido Semenza*
1930	Lord Rutherford
1931	C. H. Merz*
1932	Sir Oliver Lodge
1933	Sir Frank E. Smith
1934	F. B. Jewett*
1935	Sir William Henry Bragg
1936	André Blondel*
1937	Sir John Snell*
1938	W. D. Coolidge*
1939	Alexander Russell
1940	A. P. M. Fleming*
1941	Peter Kapitza
1942	Sir Archibald Page*

* AIEE Member.

for the needle in the haystack, the prize going to the successful finder while the efforts of the others served only to scatter the hay in all directions. Organized invention has changed the entire process. Each man is given a section of the hay to search. The man who finds the needle shows no more 'genius' and no more ability than the others who are searching different portions of the haystack."

According to my experience the act of invention is very different from the search for or the finding of the needle in a haystack. The pernicious implication of the illustration is, however, that an invention made by a dumbbell, working in an inefficient way, is an act of genius which should be rewarded by a patent, while a patent on the *same invention* made by an individual in an efficiently organized group should for this very reason be declared invalid. Here again there is not only a failure to give an incentive to invention, but actually a premium is put on inefficiency, stupidity, and lack of co-operation.

These two examples are typical of the many ways in which our Government is attempting to remove the incentives which have so greatly aided our past scientific and industrial progress. There seems to be no realization on the part of our Government that the benefits that mankind has received, in peace and in war, through progress in science and invention is of a different order of magnitude from the profits of corporations.

Fortunately, we have in our Armed Forces and in our war industries increasing numbers of men who know the real story, men who have worked with radar, men who have sunk submarines by devices that are now secret. Such men know the important part that science has played. I do not believe that there is any popular demand that scientific progress be stifled by the removal of incentives.

In England we have had frank statements from Churchill that the winning of the Battle of Britain was largely dependent on those who developed radar. I do not recall any comparable recognition on the part of our Government of the contribution of scientists to our war effort. The importance of such recognition is not that it may give satisfaction to scientists, but that it would indicate a realization of the public need of giving incentive to further progress in science. I hope that this award helps to focus our attention on this need.

Postwar Curriculums in Electrical Engineering

R. G. KLOEFFLER
FELLOW AIEE

Electrical-engineering education will be influenced in the postwar period by the lessons learned from the conduct of intensive wartime courses. An evolutionary process may be expected to accomplish needed changes as a result of the application of the engineer's powers of analysis and judgment to engineering education.

POSTWAR planning has assumed an important place in educational systems today just as similar planning is being carried on by business men, by state organizations, and by the Federal Government. This new thinking in education has caused many college campuses to be in a state of ferment with the bubbling up of new ideas and the revival of old ideas of reform in educational processes. Today one may hear of admission to the university at an early age and a concentrated course with a bachelor's degree in two years, or of a college education contained in 100 books. Conversely, there are advocates of an engineering training lasting for six years.

It is natural that an upstirring in thoughts regarding educational processes should come at this time. In the first place, humanity is in the midst of a world revolution as well as a world war. The world revolution began two decades ago and has been spreading rapidly during the past decade. It has been marked by the rise of totalitarian governments and highly centralized governments in the so-called democratic nations. Since entrance of the United States into this global struggle its educational institutions have been giving new types of intensive accelerated and objective training to speed the work of industry, the government, and the various branches of the Armed Forces. A natural question now is what has been learned in this special war training that can be applied to postwar college education.

A second cause for postwar thinking in education arises from the fact that the United States is a peace-loving nation. We did not wish this world war but once we became involved it has been our will to see it through and to take measures that will prevent a repetition of this conflict. Somehow, we have come to feel that we are to blame in a measure for this unhappy world situation. And if we are responsible in any way, then the education of our youth in the past must be at fault. From this arises our desire to change the education of the youth so that he may understand the economic and political problems of the world and thereby work for a lasting period of peace in which Americans may play a leading role.

The engineering schools of our colleges and universities have been solving many war-time problems in new kinds of objective educational training under the Engineering, Science, and Management War Training Program, Army Specialized Training Program, and the *V* programs of the Navy. These schools are now facing some postwar problems in designing new courses for returning veterans and they

Table I. Vocational Courses in Electricity

	Hours Per Week
I. Electrician	
First semester	
Mathematics (arithmetic, algebra, geometry, elements of trigonometry)	3
Principles of electric circuits and machinery	6
Electric circuits and machinery laboratory	6
Mechanical drawing (or blueprint reading)	6
Business-letter writing	3
Second semester	
Bookkeeping	3
Electrical codes and wiring laboratory	20
Appliance and motor repair laboratory	4
Electric lighting	3
Electives	2
II. Automotive electrical mechanic	
First semester	
Same as I	
Second semester	
Bookkeeping	3
Automotive electric laboratory	12
Radio-receiver theory	3
Automotive radio laboratory	12
Electives	3
III. Radio service	
First semester	
Same as I	
Second semester	
Radio theory	6
Radio laboratory	20
Bookkeeping	3
IV. Refrigerator service	

Essential substance of a conference paper presented at the AIEE summer technical meeting, St. Louis, Mo., June 26–30, 1944.

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are sure to face many more problems when the war comes to a close. Some new courses will be required for rehabilitation of veterans being released daily. Other courses will be required for training thousands of soldiers who will elect the benefit of education under the so-called "GI Bill of Rights." More thousands of college students who entered the Armed Forces before completing college will return to complete their education. Many high-school graduates who secured training under the ESMWT program will have a desire to go to college when the war is over. Other schools which have built up statewide training programs under ESMWT may wish to continue a similar type of extension training through state financial assistance. The combined result of these sources of students desiring college and university training will be to increase college enrollments to $1\frac{1}{2}$ or perhaps two times their prewar level.

The types of courses which will be required to fill the near future and after war training programs are as follows:

1. Vocational courses.
2. Refresher courses.
3. Gap-filling courses.
4. Regular college courses.

The vocational courses will be of the technical-institute or trade-school type. They will be similar to some of the objective training courses under the ESMWT program. These courses should be designed to fit the needs of men past 25 years of age who desire a short intensive training to fit them for some trade or business. They may extend over a period of one or two years and they will be mainly of the noncollege level.

The strain of war-time conditions is likely to make many returning soldier students feel that they have forgotten much of their previous college work. Likewise, some who graduated several years ago may desire to return to college for a year to take graduate work. For these men it would seem that refresher courses, such as found an important place in war training, will be needed in mathematics and the basic subjects in electrical engineering.

Another problem facing the engineering schools is the evaluation of the college credit to be allowed to the soldiers who have taken the accelerated courses in the Army and Navy programs. Many of us have already faced this problem in some degree and we know of the headaches which lie ahead. One possible aid to a solution lies in the gap-filling courses suggested in item 3. This means the organization of special courses to fill the gaps which exist between the regular courses in the electrical-engineering curriculum and the similar abbreviated courses taken in the accelerated Army and Navy programs. Such courses will contain both refresher and new material and obviously may differ from school to school.

As a more specific suggestion of the courses to be offered in vocational training in the field of electrical engineering, the outline in Table I is offered.

These proposals for vocational training are designed to have a common plan for the first semester for all courses with the specialized training deferred into the second semester. If the period of two semesters is inadequate, the program may be expanded and cultural or other courses added. Again, some men may be planning to go into business for themselves and may wish to combine two or more specialties (such as radio and refrigerator service) for operating in small communities.

Electrical-engineering teachers prefer to leave education of the vocational type to the trade schools, night schools, and technical institutes which conducted this work in prewar times. Unfortunately, the demand for this type of training for a few years after the war is likely to exceed the capacity of the former schools. Hence, many engineering schools may feel it their duty to co-operate in this training. This training program will present problems in three ways:

1. In arranging appropriate administration.
2. In finding suitable laboratory facilities.
3. In finding suitable teaching personnel.

It would seem desirable to handle the administration of this work in a separate division or branch of the college or university. For laboratory facilities it may be desirable to find buildings off the campus. In the case of the department of electrical engineering at Kansas State College it is expected to hold the recitation classes on the campus but to place the vocational type of laboratories in rented space off the campus. Use of the regular teachers for the recitation classes and for supervising the vocational laboratories and of experienced tradesmen for conducting the vocational-laboratory work is planned.

The refresher type of courses suggested under item 2 may consist of the following:

1. Refresher in mathematics (algebra, trigonometry, analytics, calculus, differential equations) ..... 5 credit hours
2. Refresher in electric circuits and machinery ..... 5 credit hours

The first course should be taught by the department of mathematics following an outline suggested by the department of electrical engineering. The second course should be taught by the department of electrical engineering using co-operating teachers for various parts of the course.

The gap-filling courses are a matter of individual concern for each school of engineering. The content of these courses will depend upon the option followed by the student in his ASTP training. It will also depend upon the curriculum of the college in which he matriculates after the war. As a specific example, the student who has taken the communication option in ASTP and enrolls in electrical engineering at Kansas State College would need a gap-filling course to make up a deficiency of one credit-hour recitation and one credit-hour of laboratory in d-c machines and three credit-hours of a-c machinery recitation and one credit-hour of a-c machinery laboratory. Other deficiencies may exist in mathematics, mechanics, and so forth.

The regular college training program after the war opens up a new subject for thought and discussion. Today our regular civilian students in engineering are gone except for a handful of 4-F's and boys under 18. Further, it appears that these civilians are gone for the duration. Their departure offers us a rare opportunity to make a complete overhauling of the curriculum in electrical engineering.

In approaching the stern realities of curriculum changes the recent report of the Society for the Promotion of Engineering Education committee on recommended changes in engineering curriculums should be considered. For present considerations two items of this report are important. First, the committee recommends that engineering curriculums should be revised to include a minimum of 20 per cent of work in nontechnical subjects, the field of the humanities, and social sciences. Second, the committee recommends that the basic engineering curriculum should be held to four years. If these recommendations are accepted for present discussion, the problem which faces electrical-engineering staffs is as follows:

1. Increase the nontechnical content of the electrical-engineering curriculum to 20 per cent or more.
2. Add new required courses in the field of electronics.
3. Hold the basic engineering curriculum to four years.

For years the electrical-engineering departments have been under a pressure from within and without to increase the subject matter in the curriculum. This pressure arises naturally from new discoveries, new applications, and the increase of knowledge in the field. Today with the pressure near the bursting point, the suggestion comes to us to increase the nontechnical content. At the same time we know that wartime discoveries and applications in the field of electronics compel us to add *required* work in electronics for all electrical-engineering students.

The task of introducing the additional material without impairing the basic subject matter and without increasing the length of the curriculum appears hopeless at first, so let us analyze this problem. The first question that arises is why is the additional nontechnical subject matter necessary. For years the idea of more nontechnical subject matter has been discussed. Suggestions have come from within and without the engineering profession that

more cultural or more liberalizing courses should be introduced into the engineering curriculums. Many are likely to resent any suggestion that the engineer lacks in culture or liberal thinking. The word culture is associated with the characteristic features of a stage of advancement in civilization. The present is often called the "machine age." Future historians are likely to attribute the culture or civilization of today to the work of the scientist and engineer. Today, buildings, factories, transportation, communications, power plants, entertainment via radio or screen, and all the conveniences of home life are the handiwork of the engineer. If the engineer is the creator of present-day culture or civilization, how can he be accused of lacking in culture?

The word liberal applied to engineering-training probably means broadminded or not narrow. Engineering training in the past has specialized in mathematics, mechanics, the physical sciences, and has contained a fair content of economics, English, history, and public speaking. All of these subjects should help to make a man broadminded. Some may think of the engineer as narrow because he is usually intensely interested in his work. Yet the same thing can be said of other professional men such as doctors, dentists, and business men. Hence the engineer is not likely to give much weight to the statement that he lacks in culture or liberal training.

However, engineers do have two important weaknesses. First, many engineers do not understand human beings. This weakness is understandable because the engineer is interested in and works with material things. He likes to plan, build, and operate machines. Hence he is inclined to neglect the human element. In the second place, the engineer may not be interested in community affairs and he may shun questions of state and politics. Because of this lack of understanding of human beings and civic affairs, the average engineer is not a diplomat, a politician, or a good salesman.

One of the big opportunities for the man of engineering training is in executive positions and the general field of management. The world of today is in near chaos because economic, political, and social organizations have failed to keep pace with the developments of science and engineering. Hence it seems very desirable that steps be taken to awaken the engineer to his duty toward society as well as his duties in his professional world.

If these weaknesses in the armor of the engineer are granted, then there may be a need for training which will increase his understanding of human nature, improve his ability to get along with people, help him to understand social problems, and teach him how to handle people in business and government affairs.

The introduction of nontechnical courses into the electrical-engineering curriculum raises many questions. Perhaps the distribution of these courses comes first. The distribution commonly suggested is three credit hours in a nontechnical course each semester, with an additional three credit hours in the first semester of the junior year. This wide distribution has the advantage of spreading out the technical work and thus tends to lighten the over-all load throughout the four-year period.

Table II. Subjects Generally Covered in the Four Major Fields of Knowledge

I. Physical science	III. Social science
A. Chemistry	*A.* Economics
B. Physics	*B.* History
C. Mathematics	*C.* Political science
D. Astronomy	*D.* Sociology
E. Geology	
II. Biological science	IV. Humanistics
A. Botany	*A.* Speech
B. Zoology	*B.* Music
C. Entomology	*C.* Art
D. Microbiology	*D.* Philosophy
	E. Logic
	F. Literature

The second question regarding additional nontechnical courses is what shall be offered. In answer to this there are several schools of thought. One favors the Chicago plan, which assumes that a complete broad education should embrace the four major divisions of knowledge. These fields are given in Table II.

Most of the courses given in engineering fall in part I or the field of physical science. Educators who favor the Chicago plan and who are outside of the field of engineering feel that the engineering curriculum should contain more courses covering the fields of biological science, social science, and the humanities. At present electrical-engineering curriculums are devoid of any work in biological science and contain a small but varied amount of work in social science and the humanities. These advocates of the Chicago plan recognize that only a limited amount of time can be devoted to a study in the fields of biological science, social science, and humanities without weakening seriously the technical training of the engineer. Accordingly, these advocates suggest the introduction of comprehensive courses in the last three fields of knowledge. Since the word comprehensive may mean different things, the following explanation is offered. A comprehensive course in social science would weave together the economic development, the political development, and the social development of a people, giving the historical setting in such a way as to teach basic theories of economics, politics, and sociology. As another example, social sciences and humanities might be woven together into a six-credit-hour comprehensive course. To do this, history would be divided into periods and in each period the discussion would cover the economic and social status, the form of government, the type of music played, the sculpture, the painting, the literature, the philosophy, and thinking of the men of that day. Obviously, the preparation of comprehensive courses would require the co-operation of many teachers and the actual teaching might require the services of several specialists in order to cover all phases of the subject. In the hands of high-grade teachers and specialists in their field the comprehensive course may broaden the training of the technical student. In the hands of less efficient teachers the course could become a hodgepodge and a waste of the student's time. The Universities of Chicago and Florida use the comprehensive courses and other schools are giving them some consideration.

Table III. Tentative Electrical-Engineering Curriculum

Nontechnical Courses and Electronics

Freshman	
College rhetoric I 3	College rhetoric II 3
Sophomore	
American history . . . . . 3 (From the world point of view)	20th century world history . . . . . 3 Principles of electronics 2
Junior	
Economics I . . . . . 3 Political science, or Philosophy, or Biological science 3	Public speaking . . . . . 2 Technical reports . . . . . 1 Electronics . . . . . 4 Electronics laboratory . . . 2
Senior	
Literature and music . . . . . 3 (Comprehensive or appreciation course)	Art (architecture, painting, sculpture . . . . . 3 (Comprehensive or appreciation course) Total nontechnical credit hours 27

The second school of thought regarding the content of nontechnical courses in engineering curriculums has been expressed by the special committee of the SPEE referred to earlier. This committee recommends the introduction of additional courses in the field of the social sciences and the humanities. This same suggestion has been current in the papers and expressions given in SPEE meetings for the past 20 years. Hence, this recommendation follows the idea of evolution and not revolution. In accordance with this recommendation, the department of electrical engineering of Kansas State College has been having many discussions in recent months. A tentative proposal which might serve as a basis for discussion has been developed, as shown in Table III.

The third question regarding the introduction of nontechnical courses is what shall be omitted from the present curriculum. That question can be solved in two ways:

1. Omission of certain courses now in the curriculum.

2. Shortening the credit-hours allotted to some technical courses.

One may begin by studying critically the courses in the curriculum and making each one justify its existence. The final elimination tests are rather difficult.

Again, one may find that some courses can be shortened through the elimination of obsolete or less essential subject matter. At Kansas State College thought is being given to the omission of mechanism, machine tool work (shop), one credit hour of d-c machinery, and electric-machine design.

In the last analysis, electrical-engineering departments will be guided by the recommendations of the SPEE, by their own views and experiences, and by certain local factors existing in each college or university. In making changes they will not be stampeded by wild ideas of so-called educational experts or by long-haired visionaries, but rather they will change courses and curriculums through an evolutionary process instead of a revolutionary one. The engineer may be trusted to apply his powers of analysis and judgment to needed changes in engineering education in the same way that he does in his daily professional problems.

Electronic Protective Systems

MAXWELL H. A. LINDSAY

Alarm systems that are actuated by changes in capacitance or interruption of invisible rays recently have been added to the older electric systems for protecting safes, vaults, and premises. The automatic preventive systems used for protection of property against unlawful entry and for the detection of fire in air-duct systems are reviewed in this article.

IN normal times electrical protection through the use of protective signaling systems has been used widely to protect industrial and mercantile premises and banks, but with the advent of the war, a host of protection engineers have been making serious studies relative to plant protection. As used herein, the term protective signaling is confined to the control of property and life hazards involved in fire, intrusion, and related risks. The functional technique of such protective devices does not differ greatly from that employed in the code signaling and communication field, but because they are emergency systems, infrequently used, their reliability must be exceptionally high. Protective signaling systems,[1] however, are definitely not in the communication field, as the only use of communication facilities in these services is for signaling between the protected premises and the central receiving headquarters.

Utility and industrial plants may be protected by preventive and supervisory electric protective systems. The preventive systems are designed to summon emergency assistance in the event of intrusion into the protected premises, or upon the occurrence of fire. The supervisory systems are designed to supervise personnel movement throughout protected plants and in the event of abnormal conditions in mechanical and electrical equipment to institute corrective measures in sufficient time to prevent damage or loss. This article will be confined to the automatic preventive systems used for the protection of premises or property boundaries against unlawful entry or intrusion and for the detection of fires originating in air-conditioning, ventilating, and other air-duct systems.

The scientific principles or phenomena on which these systems depend may be considered according to their appearance in the frequency spectrum. First are the sound-detection systems which are used for protecting vaults containing valuable or essential material and for detecting intrusion through fences. These systems operate in the audible portion of the spectrum between 100 and 3,000 cycles per second. Higher in the spectrum at about 200 kilocycles are the body-capacitance alarm devices. Here electromagnetic waves provide an intangible protecting barrier which when entered will sound an alarm. Finally, in the infrared region is the photoelectric intrusion-detection system and in the visible spectrum the smoke-detection system.

The microwave band with wave lengths of about 50 centimeters is full of promise for the future, and systems utilizing reflected microwaves have been found effective.[2]

Essential substance of an address presented before the AIEE New York Section, March 15, 1944, in New York, N. Y.

Maxwell H. A. Lindsay is engineering supervisor, American District Telegraph Company, New York, N. Y.

SOUND-ACTUATED VAULT-ALARM SYSTEMS

Electric alarm systems to signal an attempt at entry of safe-keeping vaults by burglars have been used for more than 50 years, and thousands of such systems have been installed. The most important single principle now employed in them is that of sound or vibration detection. While the early devices were comparatively crude, utilizing carbon detectors and no electrical amplification of the signal, the modern systems have great sensitivity, stability, and flexibility of adjustment to meet various local conditions. In ordinary times, these systems find use mainly in bank and fur-storage vaults. Under present conditions, however, vaults are doing double duty for the safe keeping of tools, dies, patterns, blueprints, transformers, secret devices, documents and formulas, codes, bomb sights, narcotic drugs, art, and so forth. Consequently, protection systems of the sound-operated type are in great demand. Examples of their use are the vaults of the United States mints at San Francisco, Calif., Denver, Colo., and Philadelphia, Pa.; the great gold vaults at Fort Knox, Ky.; and the vaults of the Bureau of Printing and Engraving and the National Archives at Washington, D. C. The last installation is the largest single application of microphonic-burglar-alarm protection in the world. More than 200 individual detectors and 150 amplifiers are installed, and the signal control room has much the appearance of a small-sized telephone central office.

A sound-detector alarm consists of one or more acoustically sensitive devices, such as microphones, installed within the protected vault and connected to control equipment which is responsive to the electric-current changes generated by the microphones as a result of noise developed

Table I. Intensity of Sound Sources

Item	Intensity in Decibels
Victory siren at 100 feet	135
American District Telegraph sound test unit at 10 feet	100
Electric hammer	90
Torch attack on vault wall	80
Inside fur vault	30–40
Inside bank vault	25–55
Quietest United States Archives vault at night	12

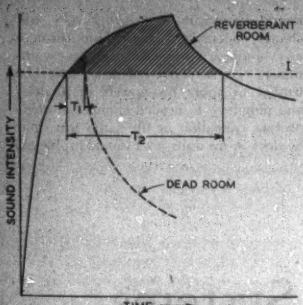

Figure 1. The growth and decay of a short sound impulse in rooms or vaults having different absorptive qualities

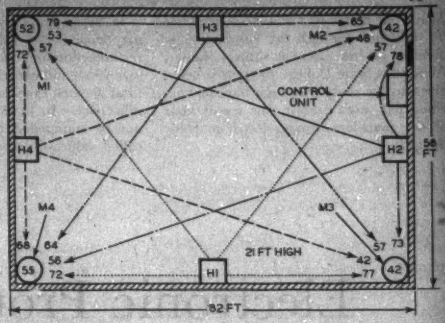

Figure 2. Plan view of the components of a sound-detection system installed in a large fur vault

Attenuation of the test sound of 100 decibels along various paths is shown by the figures at the ends of the broken lines

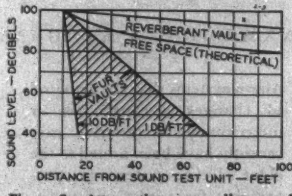

Figure 3. Attenuation versus distance of sound in various types of vaults

within the vault from a mechanical attack on the enclosing surfaces. Many factors influence the design and application of this intrusion-detection system. Normal noise within the closed vault is usually the controlling condition, for it becomes evident that the limiting factor in the protection of a given vault is the ratio existing between the normal ambient noise level within the room and the noise level which would result from an attack upon the structure. The ambient noise level is influenced of course by the exterior noises, the vault construction, and any interior source of noise such as blowers, adjacent elevators, or the hydraulic system in the building. The intensities of some common sounds and noises are listed in Table I. Like the human ear, sound detectors must be capable of responding to a reasonable part of this range and the associated amplifying system must therefore permit adjustment of sensitivity consistent with the noise conditions.

The contents of the room have a great effect on the sound intensity.[3] Figure 1 illustrates approximately the manner in which sound intensity behaves in a reverberant room as compared to a nonreverberant room from a source of short duration, as, for example, a hammer blow on one of the boundary walls. If the line I represents the sound intensity required to actuate a given alarm system, it is evident that the reverberation time of the vault in which the system is installed will have a substantial influence upon the ultimate operation, because this factor controls the length of time, T_1 or T_2 that the sound level remains at or above the value necessary to operate the system from a given source. Thus a system which might be sensitive enough for use in a reverberant vault might not do at all for one deadened by thousands of furs or tens of thousands of blueprints.

Figure 2 is a plan view of a large fur vault protected with a sound-detection system or Phonetalarm. When fully stocked, the vault contains 40,000 furs worth about $10,000,000. The protection is provided through only four sound detectors, M_1 to M_4, located one in each corner of the vault at ceiling level. They are tested each hour from the central station by sequential actuation of the sound test units located on the vault walls. This figure also illustrates the reduction in intensity of the test or attack sound caused by the absorption of the furs as the sound travels from the sound-test unit to the microphones along the clear space between the furs and the wall or ceiling. The figures in the circles representing the sound detectors in the four corners of the vault indicate the ambient noise level with the door closed and with the vault stocked with furs. Normally, the four sound-test units H_1 to H_4 are inactive but when operated for test they create a sound intensity of 100 decibels ten feet away.

As the test sound progresses from unit H_1 to each of the four detectors it is reduced to 57 decibels in going to M_1 and M_3, to 77 in going to M_2, and to 72 in going to M_4. Similar reductions occur with the sound from the other units. In the case of H_4 it will be noted that the reduction is at least 58 decibels, because the sound measured at M_2 is no higher than the ambient level.

Data compiled from actual measurements in such vaults are plotted in Figure 3. The upper curve shows the very small reduction in sound intensity as the distance increases between the test unit and the microphone in a live or reverberant vault such as a bank vault or an unstocked fur vault. The next curve, for reference purposes only, is the theoretical curve showing the relation between the signal level and the distance from the source in free space, where the intensity in the expanding wave varies inversely with the square of the distance and thus the attenuation is six decibels per distance double. The shaded area is bounded by limiting values showing the enormous sound absorption caused by the furs. Loss ranges from one to ten decibels per foot, suggesting a sort of acoustical short circuit for the sound. In large acoustically treated rooms having highly absorptive ceilings, the attenuation in noise level from the source is in the neighborhood of one-fourth decibel per foot,[4] whereas in acoustically treated air ducts[5] Sivian has shown that the attenuation per foot varies from four to ten decibels between 600 and 1,000 cycles. This resembles the losses for fur vaults. The quality of voice transmitted under such conditions is highly distorted. These characteristics require that sound-detection systems have a wide range of amplification and in practice be adjusted in accordance with the vault contents.

Figure 4 illustrates a sound-detection system installed in a nonreverberant bank vault. The piezoelectric-type detector is installed on the ceiling of the vault and connected through a shielded cable to the input of the amplifier which, along with its power rectifier and other central-station relays and circuits, is mounted in a substantial cabinet fastened to the vault wall. In practice at least two microphones are employed, but seldom more than four. Provision is made for two input channels in order to facilitate testing of individual microphone circuits. The microphones in parallel are connected to a stepped attenuator and thence to two stages of voltage gain, feeding a grid-leak detector. The normally high plate current of the output tube maintains the alarm relay, shown at the top of the amplifier, in an energized and therefore supervised condition. When a sound impulse occurs the grid of the output tube is biased negatively, lowering the plate

current and causing the relay contacts to open. These contacts are connected into the local and central station circuits through the three relays and adjusting resistors mounted on the panel to the right of the amplifier.

The equipment in the vault is connected over a single private supervised conductor to the nearest central station. There are central stations in 116 principal cities through which service is rendered to some 32,000 subscribers over about 73,000 miles of supervised metallic circuits. Figure 5 shows the interior of a typical central station. It is in continuous operation and is staffed with trained operators who record the incoming signals and uniformed and armed roundsmen and inspectors who are dispatched in emergency cars to investigate the cause of the various alarms and take the necessary action. The registers in the foreground receive the coded signals from fire-alarm boxes, watchman's stations, and sprinkler supervisory devices, while the drop units on the switchboard sections

Figure 4. Interior of safety-deposit vault showing sound detector on ceiling and amplifier control unit on wall with cabinet door open and some tube shields removed

along the wall receive alarms from directly connected subscribers having burglar alarm or other intrusion protection. By means of controls on each burglar-alarm drop the operators may signal back to the subscriber when he sends in his opening and closing signals, and also test the protection equipment periodically throughout the closed period. These drops are designed to operate on a relatively small increase or decrease in line current so that protection is secured against breaks, short circuits, or grounds in the protection devices or interconnecting circuits.

With wartime need for automatic boundary protection to aid plant guards, the use of sound- or vibration-detection systems with chain-link fences has been promoted. The object, of course, is to detect the noise caused by intrusion through or over the fence as it travels along the wire mesh, and thereupon notify the guards at distant points. Such arrangements generally reproduce the sounds audibly, but if desired the loud speakers may be cut off and the signal applied to an alarm relay. Although these systems are relatively inexpensive, they are incapable of differentiating between wanted and unwanted sounds and hence a degree of uncertainty exists as to the nature and origin of the sound representing an attack.

CAPACITANCE-TYPE INTRUSION-DETECTION SYSTEMS

Although the sound-operated intrusion-detection systems work excellently in masonry or monolythic vaults, they are not adaptable to safes and light metal cabinets, principally because the construction does not provide adequate insulation against exterior noise. Fortunately, however, the smaller metallic form of such cabinets permits other equally effective systems to be applied. For many years electrically lined wooden safe enclosures—known as cabinets for safes—were used, but as they took up much space, were clumsy because of their large doors, and had to be tailor-made for each installation, considerable relief to both the customer and the alarm company came when body-capacitance systems such as Telapproach were finally developed. These depend for their operation upon the change produced in an electromagnetic field by an intruder.[8] The field is radiated from either the object being protected, such as a safe or cabinet, or metallic conductors. These radiation sources are insulated from ground and electrically form part of the oscillating circuit of the Telapproach unit.

The system requires first a generator of electromagnetic waves, that is, an oscillator whose output is coupled to a tuning circuit. The radio-frequency voltage appearing there is then applied to a detector-amplifier, the d-c output of which depends upon the relative frequency of the oscillator and tuning circuit. The object to be protected is connected to either the oscillator or tuning circuit or both, so that any change in capacitance causes the output current to vary.

When a safe or a cabinet is approached by a person, an increase in capacitance of about one micromicrofarad occurs if he brings the palm of his hand up to within six inches of the surface, or if he walks up to within 12 inches his body adds about 20 micromicrofarads. These changes then can be detected easily by relatively insensitive circuits, but nevertheless, the circuits must be extremely stable, otherwise they might become insensitive, destroying the protection, or too sensitive, causing false alarms. Consequently, capacitance-alarm devices must contain compensating elements.

Hundreds of installations of the system have been made on safes, narcotic cabinets, and insulated racks and shelves containing valuable war material. Figure 6 shows the capacitance control unit as contained

Figure 5. Interior of a typical central station showing the drops and recorders for receiving signals from remote preventive and supervisory electric protective systems

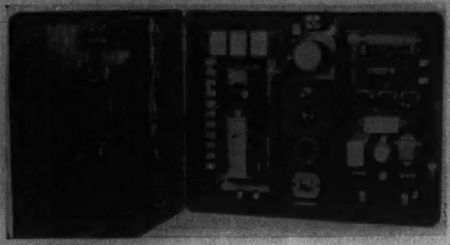

Figure 6 (left). Interior view of a capacitance alarm or Telapproach control unit

All components are rigidly mounted and protected against attack or tampering by a substantial "electrically lined" cabinet

within its protective housing. This unit is generally mounted in a position accessible for installation and inspection a few feet away from the protected safe or cabinet as shown in Figure 7. The safe itself is usually raised from the floor and placed on insulating blocks in order to avoid changes in sensitivity brought about through leakage to the floor in humid weather. The capacitance of the safe to ground is made part of the circuit by connecting the two together by a supervised pair of wires enclosed in conduit.

The control unit contains on the right panel the electronic elements of the circuit. These are associated with the tuning coil and variable capacitors mounted on the central section. The elements on the left panel are part of the local and central-station protection and test circuits as described previously for the sound-detection system. The cover of the cabinet contains a protective lining so included in the local circuit that if an attempt is made to drill or cut through the cover a cross will occur and cause an alarm. Similarly, three antitampering devices are provided, one in the rear of the housing to prevent it from being pried off the wall, another to the lower right for main-cover protection, and a third just above the round control knob to supervise the closing of the subscriber's small door inserted in the cover.

At closing time it only is necessary for the subscriber to test the adjustments of the circuit by opening the small door and operating the lower test switch. If he does not receive the proper indications he must adjust the coarse and fine controls to effect the proper capacitance balance. From then on through variations in time and humidity the circuit will compensate for and maintain the adjustments during the protective period unless some large metallic object is brought up to or removed from the proximity of the safe. The central-station operator may also duplicate the subscriber's test at closing time or an attack by cutting into the circuit an artificial capacitance of a value less than that presented by the approach of a burglar.

OUTDOOR CAPACITANCE SYSTEM

An application of Telapproach protection is the outdoor boundary capacitance system as shown in Figure 8. This system was developed originally to supplement photoelectric protection which is at somewhat of a disadvantage in protecting undulating terrain and layouts where scattered buildings and other obstacles prevent the use of sufficiently long beams to be economically practical. The antenna may be arranged to follow rough ground and to weave in and out among trees.

Figure 7. Two large safes each protected with its individual Telapproach unit

Burglar-alarm contacts on the doors insure that they are closed before the capacitance-alarm unit is tuned

The electric detecting field is formed by the conducting wires and ground in such a way that a sensitive barrier is established wherever the wires are located. Approach to within approximately two feet of the wires causes a capacitance change in the system which results in an alarm. The wires may extend equally up to a distance of about 200 feet on either side of the control unit, and are supported by insulators fastened to short posts spaced about 25 feet apart. The upper wire is about 48 inches and the lower wire about 18 inches from the ground. Thus, a single device may provide a detecting barrier approximately 400 feet long, 6 feet high, and 4 feet thick. The detecting wires in this system take the place of the safe or cabinet, and while the principle of operation is the same in both systems, this circuit is different and much more sensitive.

In applying outdoor capacitance protection, there are many factors that must be taken into account. It must first be realized that the device cannot distinguish between man and beast. A dog close by may set it off if the sensitivity is great enough to detect a man at a distance. Installation of the capacitance antenna inside of and parallel to physical barriers around the property is best. The antenna must be insulated and tightly stretched to prevent swinging in the wind which would cause a false alarm.

Telapproach is particularly applicable to such properties as public-utility plants and unattended substations, water works, manufacturing plants, ordnance depots, ammunition dumps, coastal-defense areas alien-detention camps, prisoner-of-war camps, and so forth. It may also be applied to the tops of prison walls, stone, concrete, or iron picket fences, and roof parapets. Large interior areas, where the presence of the detecting wires is not objectionable, may also be protected by this system.

By working at low radio frequencies and power, it is possible to obtain a strong induction field several feet out from the wires with an infinitesimal radiation field beyond. This characteristic of electromagnetic waves is particularly advantageous in this application as it permits the establishment of a controlled "fence" or "barrier" of protection without introducing the hazard of radiating sufficient power to interfere with radio communication. The wave length of about 5,000 feet is some 25 times the length of the detecting wires connected to the oscillator. Consequently, the possibility of efficient radiation from these wires is further curtailed, since good radiators generally have dimensions comparable with the wave length to be propagated.

The design of stable and yet sensitive capacitance-alarm systems for outdoor use is by no means a simple matter because of the very small values that have to be detected. A man a few feet from the detecting wires represents an increase in capacitance of about one-tenth micromicrofarad, whereas the capacitance to ground is in the neighborhood of 1,000 micromicrofarads. The system must therefore detect a change of about one part in 10,000 and hence must be inherently stable to at least one part in 100,000 for reliable operation. This must be accomplished in spite of changes in the dielectric constant of the air due to humidity, rain, snow, ice, solar radiation, and the like, insulation leakage, power supply variations, and all the other factors peculiar to electronic circuits.

The detecting wire is specially selected

to withstand outdoor exposure and continue to retain a high insulation resistance. The outside diameter is small enough to discourage large birds from alighting on the antenna.

Figure 9 shows the interior of the outdoor capacitance-alarm unit. The electronic components are mounted on a substantial metal chassis along with the various adjusting potentiometers, current jacks, and terminals for connecting the detecting wires. The panel to the lower left contains a local-alarm relay suitable for operating associated visible or audible signals or for actuating coded transmitter mechanisms if that principal of signaling is employed. The terminals are for connecting the power and signaling circuits to the unit and headquarters. The transformer to the right of the terminal panel is of the constant-voltage type in order that the unit will receive stabilized voltage.

A simplified schematic circuit of the system is shown in Figure 10. The right detecting wires W_1 which have a capaci-

Figure 8. A "capacitance fence," consisting of sensitized detecting wires connected to the capacitance-alarm unit, arranged to protect vital areas or buildings

tance to ground represented by C_1 are connected to a tuning inductance L_1 through blocking capacitors C_3 and C_4. The left detecting wires W_2 having a capacitance to ground represented by the variable capacitance C_2 are connected through a similar blocking or isolating capacitor C_5 to the plate inductance L_2 of the oscillator tube V_1. Inductance L_3 is inductively coupled to the grid inductance L_2 while the capacitance C_6 and resistor R_1 supply grid bias to the oscillator tube. Inductance L_2 has associated with it a link circuit L_4 connecting the oscillator circuit to the tuning circuit.

The radio-frequency voltage in the tuning circuit is rectified by the diode V_2 which is provided with a load resistor R_2. A connection is provided between the rectifier circuit and the grid of the amplifying tube V_3 through the long-time-constant circuit consisting of capacitor C_7 and grid leak R_3. A balanced alarm relay is connected in the plate circuit of the amplifying tube V_3, and the contacts of the relay connect through supervisory circuits to any form of alarm or recording device desired.

The circuit is adjusted by tuning the inductances L_1 or L_2 to change either the tuning or the frequency in such a way as to apply the oscillator output slightly off the resonant peak of the tuning circuit. Any subsequent change in the capacitance of the right or left detecting wires will create a change in the radio-frequency voltage applied to the diode rectifier, which in turn will transmit a pulse through the time-constant circuit to displace temporarily the normal output current through the relay.

AUTOMATIC FIRE CONTROL FOR AIR-DUCT SYSTEMS

In the last decade installations of air-duct systems have grown to a large total, and it is likely that the use of such systems will continue to become more common. They consist essentially of a number of ducts arranged to circulate the air in the rooms which they serve and to heat, cool, clean, humidify, or dehumidify it.

Their widespread use has brought new and dangerous fire hazards in two forms: opportunity for ready intercommunication of smoke, gases, and flames between otherwise separate fire areas, sometimes aided by forced or induced drafts; and combustion within the ducts. A duct system may have a combustible lining, or may become laden internally with dry or oily lint. Filters used in air-duct systems present fire hazards of varying degree; those of a noncombustible type which use a noncombustible adhesive are dangerous only insofar as there may be a collection of combustible lint on them whereas oil filters which utilize a combustible-oil adhesive are more dangerous. Only electrostatic-type filters do not appear to present a fire hazard. Fresh-air intake openings present a hazard because they may be so located that they can draw in smoke, flame, or heated gases from exposure fires, thus causing smoke damage and possible ignition and spread of fire in the premises served by the air-duct system.

Figure 9. Interior of a capacitance-alarm unit designed for outdoor boundary protection

To aid in controlling a fire in which a duct system is involved, it is necessary to detect the dangerous condition rapidly, and to stop automatically all forced or induced draft air flow and properly to sectionalize the ducts by means of automatically operated dampers.

In air-conditioning systems, the problem of affording fire protection, which includes protection from smoke, is complicated by the fact that smoke in the system is not necessarily accompanied by heat, and consequently the customary methods of detecting fire and initiating its extinguishment by thermal means are not necessarily applicable. Fortunately there are means of quickly detecting the presence of smoke even in very small amounts which, coupled with 125 degrees Fahrenheit fixed-temperature thermostats properly located, constitute the necessary detecting elements. The photoelectric cell is highly sensitive and rapidly responsive to interferences caused by small amounts of smoke; black or white smoke issuing from a duct in quantities just perceptible to the eye will produce a drop of about five per cent in the cell output. This is as little as need be detected, as much more smoke will ordinarily occur when the fire gets under way.

The Photronic smoke-detection system is designed for the detection of smoke in air ducts or ventilating systems. It possesses as high a sensitivity as possible without leading to a condition where false alarms would result because of dust or dirt accumulation on lenses and mirrors of the system. As shown in Figure 11, it consists essentially of a means for projecting a beam of light across the duct space where smoke is to be detected and into a receiving unit which converts the light into an electric current, decreases in which are felt by a balanced electrical circuit which gives an alarm and accomplishes other desired results. Provision has been made for distinctive trouble signals in event of failure of power or system components or of a break in interconnecting wiring. The detector is applicable to any air-conditioning or air-duct installation. It can be used in ducts up to 25 feet or more in width. It may also be used where air is

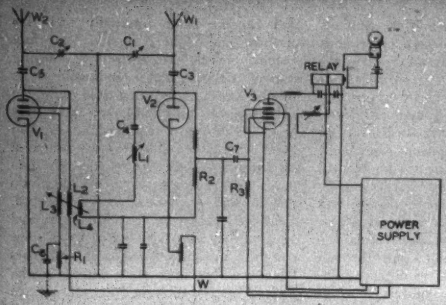

Figure 10. Simplified schematic diagram of a balanced capacitance-alarm unit

Compensation of slow capacitance changes is accomplished electrically without the use of moving parts

supplied for processes such as the cooling of ventilating motors where the presence of smoke usually would be the first indication of a fire in or near the duct or blower. This system is capable of sensing as little as one-half of one per cent smoke cutoff per foot of traversing beam.

The light source comprises a prefocused six-volt lamp and condensing lens mounted in a substantial cast housing, and adjusted to project a reasonably parallel beam of light three inches in diameter. The lamp life is about 30,000 hours or three years. The receiver comprises a housing similar to the light source, equipped with a condensing lens and photoelectric cell, the output of which constitutes a supervised circuit to a sensitive galvanometer-type relay. Means are added to secure compensation for voltage variations, decreasing brilliancy of the light source, and slow fouling of the lenses and reflectors. Alarm circuits are actuated through the relay contacts.

PHOTOELECTRIC INTRUSION-DETECTION SYSTEMS

The invisible-ray photoelectric intrusion-detection system, in contrast with the smoke-detection system, must not operate in the presence of smoke but must be capable of penetrating bad atmospheric conditions and function only when intercepted by an opaque body.

Figure 11. Smoke-detection units installed on an air duct

The light beam makes two traverses through the duct

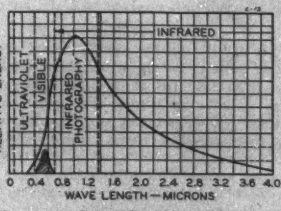

Figure 12. Spectral response of an incandescent lamp

For a number of years prior to 1935 the protection industry had been searching for a method of extending to outdoor areas the protection which was so thoroughly developed and widely used for the boundary walls and interiors of buildings. Many types of mechanical gadgets were tried but none of them offered a practical solution to the problem, chiefly because of their conspicuousness and the deleterious effect of weather conditions upon them. When the electronic art developed to the point where photoelectric cells and vacuum tubes became cheap and reliable circuit elements, it was apparent that systems using these elements could be developed to provide the protection desired. After a long period of experimentation, photoelectric protection, popularly referred to as the "invisible-ray alarm," was offered for both interior and exterior properties. The photoelectric equipment, from its original application as an indoor burglary trap, supplementing conventional protection of screens, foil, and contacts, was extended cautiously to outdoor applications, and a new method for the protection of open areas surrounding structures was thus developed.

In adapting photoelectric principles to protection problems, many unusual conditions must be met. Equipment must be designed to function reliably in spite of severe weather. The light ray must be able to penetrate heavy fog and also to work through violent rain and snow storms without sending false alarms. Different types of equipment must be available for working over different distances and under varied conditions. Protection by means of photoelectric devices is vastly different from the mere utilization of the normal run of equipment designed for such purposes as opening doors, counting boxes or persons, and turning on and off lights. Equipment for protective services must possess a large factor of safety to permit it to operate reliably at reduced voltage, with equipment somewhat out of line, with the electronic elements or lamps in a certain state of depreciation, through a reasonable degree of dust or haze, with the lens surfaces and mirror surfaces dirty, and so forth. Yet the very nature of the application requires that the system be sensitive and fast operating, with the result that inherent stability of components and the apparatus as a whole becomes a most important prerequisite. Systems that do not possess these features are prone to be

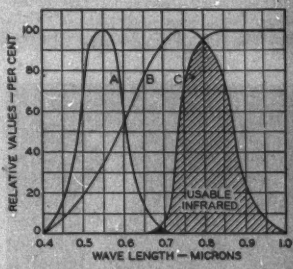

Figure 13. Comparative characteristics of the human eye (A) and cesium-silver-oxide photoelectric cell (B), and an infrared filter (C)

unstable and to produce frequent false alarms.

There are three main types of photoelectric alarm systems, namely, (1) direct-coupled, (2) pulse or capacitor-coupled, and (3) modulated. Only the last can be applied effectively and safely outdoors over any great distance, but the principles of the first two will be explained briefly.

The direct-coupled type is somewhat like the smoke-detection circuit. A photoelectric cell connected to the grid of a vacuum tube acts like a variable resistance with light, and directly controls the grid voltage and therefore the plate current. With light on the plate current is high, energizing a relay, but when the beam is intercepted the current falls and the relay is released. Obviously, any light reaching the photocell will operate the receiver, so that outdoors it is important to keep sunlight out of the receiver, otherwise the system might fail when the beam from the light source is intercepted.

The pulse or capacitor-coupled method overcomes the aforementioned objection but relies for its operation upon a rapid

reduction in the light intensity reaching the cell. Such a change is translated through the amplifier as a pulse to cause the output relay to operate. Such a system may be defeated readily by slowly intercepting the beam or blocking off the source or receiver. Furthermore, alignment of units is difficult as there is no practical method of determining the optimum setting.

The modulated system[7] employs a light source which projects a beam of light varying in intensity from zero to maximum several hundred times per second and a receiver tuned to that frequency. By resorting to this principle the receiving system can be made very sensitive, with the result that the light source can be separated from it by long distances. Furthermore, the receiving unit will respond only to the light projected from the light source, and no other light that might be accidentally or maliciously applied with intent to defeat the system will prevent it from operating normally. Daylight and artificial lights thus have no paralyzing effect that will prevent an alarm from being received should the beam be intercepted anywhere along its path.

In designing a photoelectric system, it is first necessary to select a light source which will have long life, high infrared output, high efficiency, and a concentrated radiant source. These characteristics are found best in an incandescent-filament lamp.

The amount of energy radiated by an incandescent lamp at various wave lengths is not the same, the distribution depending upon temperature as shown in Figure 12 for a tungsten filament operating at approximately 3,000 degrees Kelvin. Less than 10 per cent of the energy is within the range of visibility represented by the width of the small insert under the curve. It sometimes is asked why neon lights are not good light sources for photoelectric service; the answer is that although the spectrum is characterized by a large number of bright lines in the visible red and near infrared between 0.7 and 0.9 micron the energy of the discharge is concentrated at practically single frequencies so that the energy content falls far short of that of an incandescent source, even if the neon lamp were operated at high gas pressure and temperature.

In curve *A* of Figure 13 is plotted to a larger scale the value of a given amount of energy at each wave length in the visible spectrum as it affects the human eye. It will be seen that a given amount of green light at 0.56 microns will be roughly ten times as effective as the same amount of blue or red light. In photoelectric-protection systems it would not do to operate in the portion of the spectrum where the eye is sensitive as the beam would then be visible. Fortunately, some types of photoelectric cells are sensitive in the invisible bands, making it possible to to construct invisible-ray devices. Curve *B* of Figure 13 shows the response of such a cell which has its greatest sensitivity at about 0.80 micron, whereas that of the human eye occurs at about 0.56 micron. This means that the cell sees best where the eye can hardly see at all. All that now remains is to introduce an optical filter between the lamp and the cell which has the property of stopping those visible rays which the eye can see and passing those invisible rays to which the cell responds, as shown in curve *C* of Figure 13. It stops all light up to about 0.70 micron and then passes almost completely all radiation beyond 0.75 or 0.80 micron.

Figure 14. Outdoor-type modulated photoelectric equipment

The open cabinets of the units to the right show the tuned amplifier of the receiver unit (above) and the transformer of the light source unit (below). The center receiver is associated with a weather-housed plate-glass mirror for multiple-beam reflection

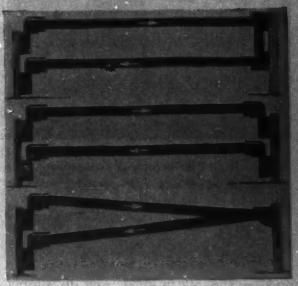

Figure 15. Pictorial representation of double beams

The apparatus shown in Figures 14 and 17 embodies these principles in conjunction with the necessary mechanical, electrical, and optical features to create a practical protective weapon.

Figure 14 illustrates the construction, various applications, and methods of installation of the instruments. Usually a single protecting beam is employed which is derived from a single light source and receiver located about three feet from the ground surface. However, double or multiple beams occasionally are required. The light source consists of an L-shaped cast housing of three sections, in which are mounted two lamps, their optical equipment, and a motor-driven light interrupter. Each of the two lenses is three inches in diameter, so that the height of the projected beam at the source is $6\frac{1}{2}$ inches and the width three inches. Internal condensation is eliminated by sealing the motor, light interrupter, and lamps in a dehydrated compartment. Vane deflectors prevent snow and ice from coating the lenses and birds from roosting or resting in front of them. Two light-source lenses are used for three reasons:

1. To make the beam area wide enough so that it will not be completely intercepted by birds.
2. To double the beam intensity.
3. To provide a spare lamp so that burnout of one lamp will not cause an alarm.

Orientation of the beam direction is accomplished independently in the vertical and horizontal direction by means of key-operated adjusting screws.

The receiver unit is similarly constructed and houses an ultrasensitive photoelectric cell and a tuned amplifier which amplifies the alternating current generated by the intermittent light falling on the photocell. The optical system used in the receiver utilizes a mirror to permit a long-focus lens of low acceptance angle to be used in a relative small housing. The diameter of the receiving lens is six inches. This, combined with the $6\frac{1}{2}$-inch height of the projected beam, insures freedom from false alarms due to birds and small pieces of paper. The amplifier contains two voltage-amplifying and tuned stages and a power-output stage supplying rectified current to

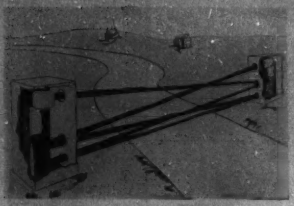

Figure 16. Pictorial representation of multiple beams for protecting entrances

Figure 17. Photoelectric protection units mounted on floats for use over water surfaces

The units are waterproof and possess great penetrating power

operate the alarm relay and to supply voltage for volume suppression. The interstage tuning is accomplished by means of two antiresonant tuned-choke assemblies peaked for the frequency to be passed. Because the frequency of the modulated light source is constant the tuning of the amplifier can be made sharp. Actually, the discrimination is in the order of 30 decibels at 100 cycles above or below the operating point. By employing automatic volume suppression the receiver may be made sensitive to small amounts of incoming light, gradually becoming less sensitive as the intensity increases. Thus there always is a small increase of output current for an increase in light, which facilitates optimum alignment of the units. A 3,000-foot beam requires about 97 per cent interception to obtain an alarm, whereas a 500-foot beam, which is about the average length in practice, requires over 99 per cent interception. In terms of light intensity units the receiver will respond to as little as 50 millionths of a foot-candle.

While single beams are generally used for protection purposes, it is often necessary to install doubled beams, that is, a "two-rail fence" to improve protection. Figure 15 illustrates schematically three methods. The upper arrangement shows a doubly reflected beam where the light source and receiver are located at one end and two mirrors arranged at 45-degree angles to the horizontal at the other end. The middle scheme calls for two entirely independent beams each having its own light source and receiver. The lower method, generally employed for shorter distances, uses only one mirror to reflect the beam. In Figure 14 the units to the left and right comprise an actual installation of the second type. In this case, the light source on the upper left projects a beam 850-feet long to the receiver on the upper right and the light source on the lower right projects an equal beam to the receiver on the lower left. In this case the ground was flat and a rather long span could be accommodated.

It is sometimes necessary to use photoelectric protection across gates, arranged to provide a complete seal for the entrance in conjunction with other photoelectric protection or perhaps capacitance protection around the rest of the property or enclosure. Figure 16 typifies such a beam system in which the light source at the upper right is mounted about six feet high and projects the beam across the road to the top of a plate-glass mirror approximately $3^1/_2$ feet high, from whence it is reflected to the bottom of an opposing mirror and eventually reaches the receiver at the upper left. The unit in the center of Figure 14 represents one end of such an installation. The beam array in this case intersects one end of the 850-foot double beam at right angles to it. The receiving unit is shown above the mirror which is surrounded by a weather-protecting housing.

An application where still larger and more powerful equipment is necessary is the protection for waterfront areas. The equipment is shown in Figure 17, and is similar in principle to that just described except that a modified optical system utilizing larger lenses is employed to obtain an effective 12-inch beam diameter. Inasmuch as this equipment is intended for the detection of harbor craft, or even small junk boats, there is no objection to increasing the beam diameter to this extent, and, by so doing, false alarms which might otherwise be caused by sea gulls are prevented. These units are mounted on bronze floats having guide shoes to engage vertical guide rails affixed to recesses in the side of the docks. Provision is made for adjusting the height of the beam with respect to the water surface, but no automatic control[8] is provided as it has been found that most applications requiring this class of equipment are located in relatively smooth water. Equipment of this type was first installed at the New York Foreign Trade Zone or Free Port in February 1937, and was in 24-hour a day service for exactly five years until the zone was discontinued. The beam projecting 3,000 feet across the out-shore end of six docks and seven slips sealed the waterfront boundaries of the zone just as the wire fence enclosed and protected the boundaries on the land side.

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Army's Power-Barge Output Is 6,000 Kva

Winslow Engineering Company photo

The eight 16-cylinder two-cycle Diesel engines driving the 750-kva generators of the Army Engineer's barge, "Electra," power source for electrical dredges, give it a total output of 6,000 kva and a 10- to 12-hour overload capacity of 25 per cent

VI—Welding's Promise of Lower Costs

JAMES F. LINCOLN
FELLOW AIEE

WE have heard a great deal about postwar planning. In fact there are more postwar planners than there are government employees, which is of itself a triumph, but we of the welding industry in looking to the time after the war have an unusual opportunity. Although arc welding, technically, is older than any of us, its actual application in manufacturing is comparatively recent, and its application to its eventual position really has not yet been started.

The fundamental reason why arc welding is important in manufacturing is that steel is about four times as strong, 2½ times as stiff, and costs about one third as much per pound as the usual cast iron. This means that if we can redesign in steel, a structure which has previously been made by casting, we require only one fourth as many pounds of metal at a price one third as much per pound as for the previous cast construction. If, instead of tensile strength, rigidity or stiffness is the important feature, then we need to use but 40 per cent as much material at one third the cost per pound, or some 12 per cent as many dollars worth of material as would be demanded for cast construction.

James F. Lincoln is president of the Lincoln Electric Company, Cleveland, Ohio.

With present outlets for expansion barely tapped, the future holds unlimited opportunities for arc welding to repeat the cycle of lighter-weight materials, less materials, and lower costs which followed its introduction into the petroleum and other industries.

The basic contribution of welding is its ability to join two pieces of steel together so that they become one piece. The result is not really a joint—it is a consolidation so that the two pieces actually become one with strengths which are as good or even better than would be obtained if the welded sections originally were made as one piece. We can be sure therefore of the following conclusions:

1. The rivet as a method of joining steel together very shortly will disappear.
2. Many castings and forgings will disappear and be replaced by welded steel.
3. Ultimately all castings will be replaced except in the very few cases where the intricacy of the shape is the controlling factor.

It might be interesting to theorize on what some of the future applications will be in present-day structures. First, it is safe to say that steel in buildings will be welded instead of riveted. By so doing a very considerable reduction in the amount of the steel used and also in the total cost of the structure will be made.

Welding is bound to have a profound effect in home construction once this activity resumes its normal stride. In this field, structural panel units fabricated to suit any design not only will do away with stud and joist framework in smaller structures, and columns and roof beams in the larger types, but also will render such buildings fireproof.

Figure 1. This large welded refinery manifold is typical of the welded construction being made in the petroleum industry

Figure 2. A typical construction view along the Big Inch pipe-line project

Figure 3. Elimination of trusses through welded design improves lighting and permits more room overhead as shown in this second-floor view of a welded factory building

Figure 4. New structural building block, a wall-frame welded unit used to simplify home construction and bring about new economies

Figure 5. Arc-welded railroad dump car weighs 12,000 pounds less than similar car of conventional design. Welded seams permit smooth interior surfaces to facilitate dumping and minimize wear and corrosion

Next, one can say that railroad rolling stock in general will be made of welded steel rather than the riveted and cast construction which is generally used at present. One may predict that the castings used largely on machine tools will be replaced with welded steel construction. Savings of over 50 per cent in cost and weight already have become common in such change-overs.

We already have seen ships of all types largely changed to welded construction, and we will see this tendency progressively strengthened, so that the ship of the very near future will not have a rivet in it.

The reduction in cost accompanying the welding process and its growing possibility of application also opens up new fields which are not self-evident. In the production of the low-cost home the use of welding can and will be of tremendous importance. It is possible to design sections of such a house in which the heating, insulation, water piping, and electric wiring all are made into a unit and to produce a house of varying size and varying appearance by the design of a few different types of sections. These sections could be made by mass production at very low cost at a rate of production far greater than any which is established now. The result of this would be a home of unique design, of very great life, and of such low cost that a saving of 50 per cent or more of the present cost could be made. It also would have the feature of mobility in that it could be taken down and moved to another location without much cost so that housing could be shifted to where it was required by a shifting population without undue cost which, with the present type of home, is a practical impossibility.

Welding in relation to transportation generally has been widely applied with the automobile and truck. On the railroads the manufacturing application is just beginning. There is not the slightest doubt that, with the possibility of very much reduced weight which aluminum and magnesium supply, welded cars can be reduced to a fraction of their present weight without too great an increase in cost. This should reduce materially the amount of weight necessary for transporting any commodity, and hence the cost would be reduced by a considerable proportion.

Possibly we are all fully conversant with the effect that welding has had in the oil industry where its application has resulted in some of the most pronounced advancements in any field of enterprise. The fact that welding was essential if low-cost production of crude-oil products was to be obtained, was perhaps one thing that speeded up its application. It is interesting to remember that were it not for arc welding the cost of oil products, such as gasoline and lubricating oil, would be much higher and would require a tremendously increased amount of crude oil. The

Figure 6. Increased production, reduced cost, and absolutely air- and water-tight seams were obtained by switching to larger-size electrodes for welding this gear gun cover

Figure 8. A typical small-parts conversion is illustrated by this valve-sheave housing. Cast-iron housing (left) cost $2.65 whereas unbreakable welded-steel housing (right) cost $1.77—an 88-cent saving

Figure 9. Savings of 440 pounds in weight were effected in this welded redesign of the older cast-constructed ice-crusher machine, with proportionate increase in appearance and durability

difference is caused by the arc-welded cracking still only possible in the light of arc welding. Greatly decreased costs of petroleum products attributable to modern welded refinery construction have made it possible to double the production of gasoline per barrel of crude oil, thus decreasing the cost of gasoline and contributing directly to the conservation of oil resources.

As compared to previous conventional methods of construction, welded design permits fabrication of the various kinds of tanks used in refining processes so that they will withstand higher pressures and temperatures and resist chemical reaction to a much higher degree.

Pipe-line and pumping equipment now is built almost exclusively by means of welding to assure maximum rigidity and lowest manufacturing and operating costs; the demand for this type construction rose about 70 per cent during a ten-year period covered in a recent survey.

The same highly desirable benefits obtained in new construction will be reflected in a further widespread adaptation of welding as a maintenance and repair tool. Restoration of pipe lines, machinery and plant, and field equipment of all kinds through use of the shielded-arc process has resulted in incalculable savings in time, materials, money, and man power. We cannot afford to overlook such advantages in the planning of economical postwar operations.

There is very little doubt that the welding of the future is going to be done more economically than the welding of the past. The cost of the equipment for doing the work will be reduced greatly as it has already during the last generation. The most significant saving will be, however, in the speeding up of the operation itself. It is anticipated that welding of the future will be two or more times as fast as has been habitually true heretofore, and it is most probable that because of this speed-up the cost of welding will be reduced considerably. As has always been true of any hand operation, there will be more and more change to machine operation which again will reduce the time of doing the job and, in turn, its cost.

One widely advocated move which has been mainly responsible for increased welding production and lowering of costs has been the adoption of larger-diameter electrodes wherever practicable. The productiveness of the operator depends on the amount of electrode metal he can apply in the form of welds in a given time. That is one of the chief reasons why the use of larger electrodes will continue to be of great importance.

It is a simple thing to say that arc welding will replace more expensive products and cheapen the products which it helps to produce. The rate at which this is done, however, is dependent on one thing and that is the imagination of the engineer in redesigning the product so that arc-welding construction can be and will be economically done. On this is dependent to a very large extent how quickly these economies become effective and on this to the same extent will depend also how rapidly this process will be developed.

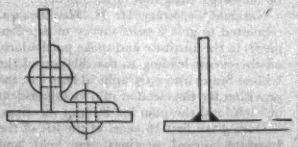


Figure 7. The fundamental simplicity of arc welding over riveted design eliminates a third connecting member as shown above in typical joined sections, with resulting economies in material requirements

If the application were obvious it would have been done long since. There will always be the conservative who believes that, because a thing has been done a certain way for a certain number of years, it must be done so indefinitely.

The individual who resents and resists change is a hard man to deal with, when the present construction is obvious and the new construction has not been made. The great boon to American industry is the American engineer who has been able to look into the future more successfully than the engineers of any other country. Because of this we are in our present fortunate condition for war production, and it is also largely because of this that we will occupy an advantageous position after we achieve peace.

INSTITUTE ACTIVITIES

Los Angeles Technical Meeting Well Received in Aircraft Center

Held in an area having extensive aircraft industries with a program predominantly devoted to electrical equipment for military aircraft, the AIEE Los Angeles technical meeting at the Biltmore Hotel, Los Angeles, Calif., August 29–September 1, was outstandingly successful. Keen interest was displayed throughout the program, which was by far the heaviest in technical content ever held by the Institute on the Pacific Coast. The registration of 561 was the highest ever obtained at a Pacific Coast meeting; 133 of these registrants were nonmembers. Distant members had been requested by the AIEE executive committee to give serious consideration to the acute travel congestion and to whether or not their attendance would really aid the war effort. Proceeds from the sale of technical papers amounted to $475.70 in contrast to a total of $49.75 at the Pacific Coast meeting in 1940.

In addition to 19 technical sessions, the program included a general session with the principal address by President C. A. Powel on "The Engineer and His Future," and a luncheon meeting addressed by Lieutenant Colonel T. B. Holliday (M '43) United States Army Air Forces, on "Aviation and the Electrical Engineer."

TECHNICAL SESSIONS

Of the 19 technical sessions, only four were outside the field of electrical applications in aircraft, including one session each on protective devices, three papers; power transmission and distribution, three papers; electronics, five papers; and industrial and marine applications, three papers. The 15 technical sessions on aircraft electrical developments included a total of 58 papers on the subjects: electric motors for aircraft, aircraft radio, aircraft ignition systems, aircraft—general, aircraft electricity, aircraft wiring, aircraft motor applications, aircraft electrical design, aircraft brush wear, aircraft lighting, aircraft power systems, high voltages in aircraft, aircraft automatic control and instruments, aircraft power equipment, and special aircraft equipment. One of the 58 papers was accepted for presentation as a conference paper; all others have been approved for Institute publication.

GENERAL SESSION

In opening the general session, Vice-President J. M. Gaylord, who presided, said this 32nd annual meeting on the Pacific Coast found the United States engaged in the most deadly conflict of all time, with thousands of members serving in the Armed Forces, other thousands in intensive war production, and some left to operate the power, transportation, and telephone systems, and other essential services. He said the technical program was offered in southern California where it would reach the maximum number of aircraft engineers, and if it would contribute to the shortening of the war the meeting would be a success.

He paid special tribute to the vision, enthusiasm, and driving force of Lloyd F. Hunt (F '38) senior electrical engineer, operations department, Southern California Edison Company, Ltd., Los Angeles, and formerly general chairman, which made the meeting possible. Mr. Hunt organized the committees, and had preparations well under way before he was called away on war work. T. M. Blakeslee (M '38) junior electrical engineer, Bureau of Power and Light, City of Los Angeles, succeeded him as general chairman. Both are past chairmen of the Los Angeles Section, and, under Mr. Blakeslee's administration, the aircraft division of the Section was organized.

Brigadier General Donald F. Stace, in command of the Army Air Forces Matériel Command, Western District, a graduate of the 1920 class of the United States Military Academy then was introduced, and extended the welcome of the Air Corps to those attending the meeting. He spoke in high terms of the contributions made by the Institute to the development of aircraft electrical equipment for military planes and especially of the sound engineering principles applied in the development of radio and radar.

He urged that there be no letdown, and that continuing efforts be exerted to make the equipment safer and more dependable through effective co-ordination among development engineers, designers, and manufacturers, to the end that the best compromises be made between good engineering installations and the most practical operation in the field, where the equipment must be maintained by mechanics with little training in electricity. He expressed the hope that the meeting would bring about mutual understanding on developments and was confident that American equipment will continue to be far better than that of the enemy.

National Secretary H. H. Henline was requested to give a brief survey of developments in the Institute and spoke particularly on the events leading to the division of the United States into geographical Districts, the provision for the election of a vice-president in each, and the plan for District meetings.

During the first 18 years of the life of the Institute, annual meetings were held, and monthly meetings were held in New York beginning in 1886 and in Chicago beginning in 1894, he reminded the meeting. On May 1, 1902, the membership was 1,549. In the fall of that year, the plan for the formation of Sections and Branches was adopted. By the end of the next 18 years, the membership had reached 11,345, and there were 36 Sections and 62 Student Branches.

A recommendation by the committee on developments following studies of desirable modifications in the fields and methods of work of the Institute, resulted in the division of the United States into 9 geographical Districts, with Canada as the tenth, and provision for the election of a vice-president in each. These changes came from the desire of the membership for closer contact between the Sections and the Institute officers and other prominent engineers to improve morale, stimulate the Sections, and develop greater interest among the younger members.

He traced briefly the establishment and later development of the District executive committees, pointing out in particular that changes have come from needs that appeared, and he spoke highly of the important place held by District organizations in Institute developments in the past 24 years. The Sections have carried on their activities splendidly despite the difficulties of the past few years, he said.

Institute activities are in excellent condition, with a present membership of about 22,000, and 73 Sections and 125 Student Branches, he added.

Vice-President Gaylord introduced President Powel, who delivered his address entitled, "The Engineer and His Future." He declared that war is a great stimulant, producing a searching analysis of the position of engineers under the criticisms that the occupation is not as secure as it should be, the remuneration is not as high as in other professions, engineers do not participate sufficiently in civic affairs, and their prestige is not sufficiently high.

In tracing briefly the history of engineering, he said that early engineers were in general not as well educated as doctors and lawyers were, theoretical training was looked upon with suspicion, and the older professions did not give engineers a warm welcome. Although, as time passed, science and engineering assumed more important places in shaping developments, engineers received scant recognition. There is still no minimum standard for the practice of engineering, he pointed out.

The American Engineering Council was intended to represent all engineering in the broader activities, especially in connection with legislation affecting engineering, but it went out of existence in 1940. There is a need for such an overriding organization, particularly to act regarding such proposals as the socialization of scientific development, according to President Powel. Engineering councils on a smaller scale are numerous throughout the country. These should be encouraged, expanded, and co-ordinated, he asserted.

A more recent manifestation among engineers, he noted, is a movement to band together for collective bargaining to improve their personal fortune, and as a result, two general schemes of collective bargaining have been tried. In one case, engineers have used their technical association as a vehicle around which to build a bargaining unit, and in the second, engineers have formed a part of a white-collar union.

Mr. Powel gave reasons why, in his opinion, neither of these schemes is suitable for engineers. He stressed the fact that what the engineering profession needs is some over-

riding association representing all branches and dedicated to the purpose of representing the profession in civic and state affairs and also capable of watching over the welfare of its individual members. He emphasized the point that such an organization could not be a side line of the Founder Societies since it would involve financing beyond their ability.

LUNCHEON MEETING

H. L. Caldwell (F '20) past chairman of the Los Angeles Section, presided at the luncheon meeting held on Wednesday, August 30, which had an attendance of 240. After expressing his gratification at the large registration at the meeting, he introduced the guests at the speakers table, and then introduced Colonel T. B. Holliday (M '43), who gave his address on "Aviation and the Electrical Engineer."

Colonel Holliday mentioned recent advertising statements that an airplane now can reach any point in the world within 60 hours, and the effect this development has had upon the thinking of electrical engineers in the aircraft field. Designers of many types of equipment can design for certain localities, but airplanes must serve through an extreme range of conditions, producing an entirely new conception of transportation.

Weight must be kept to a minimum, and space must not be larger than necessary. Hence extreme precautions in design are required to keep the necessary equipment within allowable limits. Reliability of performance must be adequate without excessively frequent attention. In protective requirements a plane with four engines is like a city with four power plants, as their problems involve the power supply bus and feeder network, the individual circuits, and the equipment itself.

The principal operating conditions, listed by Colonel Holliday, which must be taken into account are altitude, up to 50,000 feet, making blast cooling necessary; high temperatures, up to 165 degrees Fahrenheit; low temperatures, to −110 degrees Fahrenheit; vibration, in frequencies covering a wide range; sand and dust, including flint dust; salt and humidity, requiring extreme measures in packing planes and parts.

He stated that an amazing record has been established in performance of the many types of radio equipment and the suppression of noises produced by other electrical equipment, and he urged that continuing efforts be made to produce better equipment during and after the war.

AIEE Board of Directors Meets

At the regular meeting of the AIEE board of directors held at Institute headquarters, New York, N. Y., August 2, 1944, representatives of the Institute on other bodies in addition to those announced in *Electrical Engineering* (Sept. '43, pages 344–8).

Other representatives so appointed were:

H. B. Gear to the Marston Medal Board of Award for a four-year term beginning August 1, 1944; E. C. Stone to the Engineers' Council for Professional Development for the term of three years beginning in October 1944; N. S. Hibshman to the Library Board of the United Engineering Trustees, Inc., for the four-year term beginning in October 1944; W. A. Lewis to the Research Procedure Committee of The Engineering Foundation for the term of one year beginning October 1944; and Everett S. Lee to the Board of Trustees of United Engineering Trustees, Inc., for the four-year term beginning in October 1944.

The president was authorized to appoint an Institute representative on the general advisory committee and the engineering committee of the Construction Industries Advisory Committee of the War Production Board, and Past President Gano Dunn subsequently was appointed.

Vice-President M. S. Coover was designated as the AIEE nominee for the new Committee on Hertz Award, consisting of three members—one nominated by the Rural Electrification Administrator, one by the National Rural Electric Co-operative Association, and one by the AIEE.

Local honorary secretaries of the Institute were reappointed for the two-year term beginning August 1, 1944, as follows: V. J. F. Brain for Australia, A. S. Garfield for France, V. F. Critchley for Northern India, N. N. Iengar for Southern India, W. Elsdon-Dew for Transvaal, Union of South Africa.

The board voted that the chairmen of the committees on air transportation, communication, electrical machinery, power transmission and distribution, and protective devices be appointed to the committee on award of Institute prizes in addition to the members specified in Section 80 of the bylaws.

As required by the bylaws of the respective committees, the board confirmed appointments by the president as follows:

Edison Medal Committee: O. E. Buckley, A. E. Knowlton, and H. E. Strang as members for the five-year term beginning August 1, 1944, and K. T. Compton as chairman for the year 1944–45. The board elected from its own membership P. L. Alger, M. S. Coover, and S. H. Mortensen to serve for the term of two years beginning August 1, 1944.

Charles LeGeyt Fortescue Fellowship Committee: J. M. Gaylord and R. T. Henry as members of the committee for the three-year term beginning August 1, 1944.

Lamme Medal Committee: W. A. Del Mar, John Castlereagh Parker, and Philip Sporn as members for the term of three years beginning August 1, 1944.

Upon recommendation of the standards committee, the appointment of P. W. Blye as chairman of the AIEE delegation on the Sectional Committee on Acoustical Measurements and Terminology, Z24, was approved.

It was voted to contribute $350 to the National Council of State Boards of Engineering Examiners for this year, upon request of that organization.

Announcement was made of the appointment by the president of the general and technical committees of the Institute for the administrative year beginning August 1, 1944.

Minutes of the meeting of the board of directors held on June 29, 1944, and the meeting of the executive committee on July 12, 1944, were approved.

A report of a meeting of the board of examiners held July 20, 1944, was presented, and the recommendations adopted at that meeting were approved. Upon recommendation of the board of examiners, the following actions were taken: 10 applicants were tranferred to the grade of Fellow; 52 applicants were transferred and 33 were elected to the grade of Member; 183 applicants were elected to the grade of Associate; 75 Students were enrolled.

Appropriation disbursements in July amounting to $33,158.10 were reported by the finance committee and approved.

Those present at the meeting were:

President—C. A. Powel, East Pittsburgh, Pa. *Past Presidents*—N. E. Funk, Philadelphia, Pa.; H. S. Osborne, New York, N. Y. *Vice-Presidents*—J. F. Fairman, New York, N. Y.; W. J. Gilson, Toronto, Ont., Canada; R. T. Henry, Buffalo, N. Y.; C. W. Ricker, New Orleans, La.; R. W. Warner, Austin, Tex.; W. E. Wickenden, Cleveland, Ohio. *Directors*—P. L. Alger, Schenectady, N. Y.; K. L. Hansen, Milwaukee, Wis.; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; M. J. McHenry, Toronto, Ont., Canada; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; D. A. Quarles, New York, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

AIEE Officers to Be Nominated for 1945 Election

For the nomination of national officers to be voted upon in the spring of 1945, the AIEE national nominating committee will meet during the winter technical meeting, New York, N. Y., January 22–26, 1945. The officers to be elected are: a president, a national treasurer, three directors, and five vice-presidents, one from each of the even-numbered geographical Districts. Fellows only are eligible for the office of president, and Members and Fellows for the offices of vice-president, director, and national treasurer.

To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, not later than December 15, 1944.

In accordance with the provisions in the constitution and bylaws, as amended during 1935 and quoted in the following paragraphs, actions relative to the organization

MEMBERSHIP

Fellow Members of the Institute:

You have recently received a letter with an enclosed return postal asking for names of persons who would qualify in your opinion as members of the Institute. Do give us these names promptly so that proper contacts can be made. Remember, this is one of the well proved methods of obtaining new members. Your individual effort counts!

Chairman, National Membership Committee

of the national nominating committee are now under way.

Constitution

28. There shall be constituted each year a national nominating committee consisting of one representative of each geographical District, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical Districts; all to be selected when and as provided in the bylaws. The national secretary of the Institute shall be the secretary of the national nominating committee, without voting power.

29. The executive committee of each geographical District shall act as a nominating committee of the candidate for election as vice-president of that District, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The national nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The national nominating committee shall name on or before January 31 of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice-presidents as have been named by the nominating committees of the respective geographical Districts, if received by the national nominating committee when and as provided in the bylaws; otherwise the national nominating committee shall nominate one or more candidates for vice-president(s) from the District(s) concerned.

Bylaws

Sec. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical District that by December 15 of that year the executive committee of each district must select a member of that District to serve as a member of the national nominating committee, and shall by December 15, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice-president, that by December 15 of that year a nomination for a vice-president from that District, made by the District executive committee, must be in the hands of the secretary of the national nominating committee.

Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of *Electrical Engineering* (Journal of AIEE), or otherwise mailed to the Institute membership not later than the first week in March.

INDEPENDENT NOMINATIONS

Independent nominations may be made in accordance with provisions in article VI, section 31, of the constitution and section 23 of the bylaws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District concerned.

Bylaws

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (constitution), must be received by the secretary of the national nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. Henline,
National Secretary

October 1, 1944

Future AIEE Meetings

Winter Technical Meeting
New York, N. Y., January 22–26, 1945

North Eastern District Meeting
Buffalo, N. Y., Spring 1945

Summer Technical Meeting
Detroit, Mich., June 25–29, 1945

PERSONAL

K. T. Compton (F '31) noted physicist and president of Massachusetts Institute of Technology, Cambridge, has been appointed 1944–45 chairman of the AIEE Edison Medal committee of which he has been a member since 1940. Doctor Compton was born September 14, 1887, in Wooster, Ohio, and received the degrees of bachelor of philosophy, 1908, and master of science, 1909, from Wooster College and the degree of doctor of philosophy from Princeton University in 1912. He has been honored many times with the degrees of doctor of science, doctor of laws, and doctor of engineering. He was instructor in chemistry at the College of Wooster in 1909 and instructor in physics at Reed College, Portland, Oreg., in 1913. In 1915 he joined the faculty of Princeton (N. J.) University as assistant professor of physics, becoming professor in 1919 and chairman of the department of physics in 1929. In 1930 he was appointed president of Massachusetts Institute of Technology. Concurrently he has held positions in many scientific, civic, governmental, philanthropic, and industrial organizations. He was aeronautical engineer for the United States Signal Corps in 1917 and associate scientific attaché in the American Embassy in Paris, France, in 1918. He acted as consulting engineer to the Department of Agriculture and the General Electric Company from 1924 to 1930. He was a member of the Massachusetts Committee on the Stabilization of Employment from 1931 to 1933 and chairman of the institutions division of the Boston (Mass.) Community Fund in 1939. He has been chairman of the new-products division of the New England Council since 1939; member of the advisory committee to the United States Weather Bureau since 1933; member of the visiting committee of the United States Bureau of Standards since 1931; member of the National Defense Advisory Committee, chairman of the advisory committee on scientific research to the National Association of Manufacturers since 1937; chairman of the Rockefeller Foundation and its general education board since 1940. He is a past president of the American Physical Society, the Society for the Promotion of Engineering Education, and the American Association for the Advancement of Science. He served as chairman of the committee on engineering schools of the Engineers Council for Professional Development from 1932 to 1939. He is a member of the National Academy of Sciences, Phi Beta Kappa, Sigma Xi, and Tau Beta Pi. In 1931 he was awarded the Rumford Medal of the American Academy of Arts and Sciences, and he is a trustee of the Brookings Institution and Norwich University. In addition he is a member of the Optical Society of America, the American Philosophical Society, the American Chemical Society, the Franklin Institute, the American Society of Mechanical Engineers, the Institute of Aeronautical Science, and the Century Association.

F. M. Farmer (A '02, M '12, F '13) vice-president and chief engineer, Electrical Testing Laboratories, New York, N. Y., has been appointed 1944–45 chairman of the committee on the members-for-life fund. Mr. Farmer has served as chairman since the committee was organized in February 1944. Born March 28, 1877, in Ilion, N. Y., Mr. Farmer received the degree of mechanical engineer from Cornell University in 1899. After employment in the testing department of the General Electric Company, Schenectady, N. Y., from 1899 to 1901, he served as inspector in the United States Navy until 1903. In 1903 he joined the Electrical Testing Laboratories, then the Lamp Testing Bureau, in New York. In 1906 he was titled engineer and in 1912 was named chief engineer of the laboratories. From 1902 to 1906 he also was instructor in the evening session of Cooper Union Institute. He became vice-president of the laboratories in 1929 and was named consulting engineer in 1942. Mr. Farmer was a director of the

K. T. Compton

Mark Eldredge

F. M. Farmer

L. F. Howard

L. W. Clark

T. F. Barton

Institute from 1934 to 1938, vice-president for 1938–39, and in 1939 was elected president. He represented the Institute on the Engineering Foundation Board from 1935 to 1939, was elected chairman of the board in 1936, and at present is its AIEE representative. Appointed AIEE representative to the United Engineering Trustees, Inc., in 1937, he was made vice-president of the organization for 1942–43, and is currently serving as its president. A member of the AIEE Standards committee from 1919 to 1941, Mr. Farmer's extensive participation in standardization activities includes chairmanship of two committees of the American Society for Testing Materials and presidency of that Society for 1924–25; chairmanship of two committees of the American Standards Association and of its Standards council from 1936 to 1939; membership on the electrical standards committee, the United States National Committee of the International Electrotechnical Commission; and the instruments and measurements committee of the power test codes committee of the American Society of Mechanical Engineers. Other AIEE committees on which he has served are: the board of examiners, 1923–28, 1936–38; power transmission and distribution, 1920–38, 1941–42; electric welding, 1927–28, 1930–31; research, 1929–38, 1942–44 (chairman 1933–36); award of Institute prizes, 1933–36; Edison Medal 1934–40; headquarters, chairman, 1936–38; finance, 1938–42; planning and co-ordination, 1938–42 (chairman 1938–41); transfers, 1938–39; publication, 1941–44. In addition he has represented the Institute on the committees for the Charles A. Coffin Fellowship, the John Fritz Medal board of award, the Hoover Medal board of award, the Engineering Societies monograph committee. He is the author of numerous technical papers and of "Electrical Measurements in Practice," a contributor to the "Standard Handbook for Electrical Engineers," and is an associate editor of the "American Civil Engineers Handbook." He received an AIEE national best-paper prize in 1926. He also is a fellow of the American Association for the Advancement of Science, a member of the American Society of Mechanical Engineers, and a past president of the American Welding Society.

Mark Eldredge (A' 14, M '20, F '33) chief, military and industrial unit, power division, Office of War Utilities, War Production Board, Washington, D. C., has been appointed 1944–45 chairman of the AIEE committee on constitution and bylaws of which he has been a member since 1941. He was born in Woodbury, N. J., May 17, 1882, and was graduated from Worcester Polytechnic Institute in 1906. He was employed in the testing department of the General Electric Company, Schenectady, N. Y., in 1906 and 1907, and by the United States Reclamation Service in Williston, N. Dak., in 1907 and 1908. He became superintendent of power for the Gilson Asphaltum Company, Dragon, Utah, in 1909 and operated several electric garages in Colorado Springs, and Denver, Colo., in 1910. From 1911 to 1913 he was professor of electrical engineering in Ewing College, Allahabad, India. Joining the Tata Hydro-Electric Power Supply Company, Bombay, India, in 1913 as electrical assistant to the textile engineer, he became distribution engineer in 1915. During World War I he was commissioned a captain in the Quartermaster Corps of the United States Army. Returning to India in 1919, he was employed as superintendent of power by the Ludlow Jute Company, Calcutta. From 1922 to 1924 he was assistant engineer with the Electric Bond and Share Company, New York, N. Y., and in 1924 became chief engineer for the Memphis Power and Light Company. When the company was purchased by the City of Memphis in 1939 he continued as director of the city's Light, Water, and Gas Division only to resign in 1940. Since then he has devoted his time to various war agencies. He was appointed chief of the munition-plant section of the construction division of the Council of National Defense in 1940, and in 1941 he organized an agency to alleviate the tightened steel supply situation in the shipbuilding industry. Later that year he joined the power division of the WPB to handle problems of power supply to the Army, Navy, and Maritime Commission and eventually to the rubber, chemical, petroleum, and other industries. He was chairman of the AIEE Memphis Section, which he organized, in 1930 and 1931. In 1939 he was elected a director of the Institute and in 1935 vice-president for the Southern District. His AIEE committee memberships include: power transmission and distribution, 1933–39; Sections, 1934–37; Institute policy, 1937–38; safety, 1937–42; Edison Medal, 1939–43; Lamme Medal, 1940–43.

T. F. Barton (A '12, M '18, F '30) commercial vice-president, and district manager, General Electric Company, New York, N. Y., has been appointed 1944–45 chairman of the AIEE headquarters committee of which he has been a member since 1942. Mr. Barton was born December 25, 1885, in Orangeburg, S. C., and was graduated from Clemson Agricultural College in 1906 with the degree of bachelor of science in electrical engineering. He immediately entered the testing department of the General Electric Company, Schenectady, N. Y., and in 1909 was transferred to the d-c engineering department. From 1911 to 1917 he was engaged in field engineering for the company's New York district office. He returned to Schenectady as section head in the central-station engineering department in 1917 and, except for a brief assignment in South America and Europe, remained there until he was transferred to New York as district engineer in 1927. He was appointed assistant manager of the district in 1939 and manager in 1941. In 1942 he was named commercial vice-president. Active in Institute affairs, Mr. Barton was elected AIEE vice-president for District 3, New York City, in 1939 and a member of the AIEE board of directors in 1940. He was chairman of the New York Section for 1932–33. Mr. Barton has served on many AIEE committees and special committees including: membership committee, 1917–18; the board of examiners, 1934–37, 1940–42; committee on transfers, 1935–36; the finance committee, 1939–44 (chairman 1942–44); committee on industrial power applications, 1939–42; marine transportation, 1940–42, the Edison Medal, 1940–44; planning and co-ordination, 1942–44. He has been vice-president of the Electrical and Gas Association of New York and of the Engineers Club of New York. A number of patents have been issued in his name, and he has twice received Charles A. Coffin Foundation awards for his contributions to the electrical industry.

L. W. Clark (A '25, M '42) engineer, electrical system, Detroit (Mich.) Edison Company, has been appointed 1944–45 chairman of the AIEE committee on electric welding of which he has been a member since 1938. He was born April 9, 1901, in Evansville, Wis., and was graduated from the University of Wisconsin in 1923 with the degree of bachelor of science in electrical engineering. He was associated with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., from 1923 to 1927 as student engineer and general engineer. In 1927 he was employed as investigating engineer for the eastern district of the A. C. Nielsen Company, Chicago, Ill., and in 1928 joined the Detroit Edison Company. His first positions were assistant project engineer and design engineer. Since 1931 he has been engineer in the planning division of the electrical system. Mr. Clark served on the AIEE committee on industrial power applications from 1942 to 1944. He is a member of the Association of Iron and Steel Engineers, the American Welding Society, and Tau Beta Pi. He has served as chairman of the sectional committee on electric welding apparatus of the American Standards Association.

L. F. Howard (A '22, M '25) telephone engineer, operations and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been ap-

J. A. Elsi

W. B. Kouwenhoven

W. C. White

pointed 1944–45 chairman of the AIEE membership committee of which he has been a member since 1941. He was born July 17, 1893, in Princeton, N. J., and immediately after his graduation from Worcester Polytechnic Institute in 1914, he entered the long-lines department of the American Telephone Company. He was engaged in field work and the preparation of specifications until 1917 when he was transferred to Baltimore, Md., where he continued in field work. In 1918 he was made district inspector, and in 1919 returned to New York to the office of the engineer of inside plant in the long-lines engineering department. In 1924 he was transferred to the central-office engineering branch of the department of operation and engineering in which he deals with design, maintenance, and installation problems as consultant with the operating companies of the Bell System. He is a member of Tau Beta Pi and is active in civic affairs in Scarsdale, N. Y.

W. B. Kouwenhoven (A '06, M '22, F '34) dean of the school of engineering and professor of electrical engineering, Johns Hopkins University, Baltimore, Md., has been appointed 1944–45 chairman of the AIEE committee on applications of electricity to therapeutics, of which he has been a member since 1941. Doctor Kouwenhoven, who was born in Brooklyn, N. Y., January 13, 1886, received from Polytechnic Institute of Brooklyn the degrees of electrical engineer in 1906 and mechanical engineer, summa cum laude, in 1907. He earned a diploma in engineering, summa cum laude, in 1913, and the degree of doctor of engineering, magna cum laude, in 1914, from the Karlsruhe Technische Hochschule, Baden, Germany. As a member of the faculty of the Polytechnic Institute of Brooklyn from 1907 to 1910, he was assistant in physics and instructor in physics and electrical engineering. After his return from Europe in 1913 he was instructor in electrical engineering at Washington University, St. Louis, Mo., and in 1914 joined the staff of Johns Hopkins University as instructor in electrical engineering, becoming associate in electrical engineering in 1917. On leave of absence from 1919 to 1920, he was employed as engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn. He resumed his duties at the university as associate professor in 1920 and was appointed professor of electrical engineering and assistant dean of the school of engineering in 1930. In 1938 he became dean of the school of engineering. He ha been consulting engineer to the United States Bureau of Mines and the United States Bure:u of Standards. Author of numerous papers, he was especially honored for two of them: by the International Electrical Congress in 1932 and by the Resistance Welders Manufacturers Association in 1942. His many AIEE activities have included the offices of chairman of the Baltimore Section in 1930 and counselor of the Johns Hopkins University Branch from 1938 to 1941, and membership on the following committees: instruments and measurements, 1925–41; (chairman 1933–36); Sections, 1925–34 (chairman, 1927–30); research, 1933–41 (chairman, 1936–38); Lamme Medal, 1938–41 (chairman, 1939–41) telegraphy and telephony (now communication), 1919–20; electrophysics (now basic sciences), 1924–33; co-ordination of Institute activities, 1927–30; safety, 1933–43; electrochemistry and electrometallurgy, 1935–42 (chairman, 1941–43); award of Institute prizes, 1936–38; Standards, 1940–43; Institute policy, 1940–42; Edison Medal, 1935–37, 1939–44 (chairman, 1943–44). Doctor Kouwenhoven served as vice-president of the Institute, 1931–33, and as a director, 1935–39.

L. A. Kilgore (A '29, M '37) section engineer, large a-c motor section, transformer and generator department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed 1944–45 chairman of the AIEE committee on electrical machinery of which he has been a member since 1938. Born in Levitt, Nebr., August 10, 1905, Mr. Kilgore received from the University of Nebraska the degree of bachelor of science in electrical engineering in 1927 and the degree of electrical engineer in 1934 and the degree of master of science in electrical engineering from the University of Pittsburgh in 1929. He attended the Westinghouse Engineering and Design School in 1927, and in 1928 was employed in the design of turbine generators for the Westinghouse Company. He continued with this work and development work on large electric machines, and large a-c generators until 1936. In 1936 he was transferred to the design of mercury-arc rectifiers and ignitrons. Since 1938 he has been in charge of the design of large a-c motors. He has written several technical papers, and he taught in the graduate course offered in 1936 and 1937 through a joint Westinghouse–University of Pittsburgh program.

M. K. Brody (M '42) technical director, McCall Test Rooms, McCall Corporation, New York, N. Y., has been appointed 1944–45 chairman of the AIEE committee on domestic and commercial applications of which he has been a member since 1942. Born October 15, 1905, in Southampton, N. Y., Mr. Brody was graduated from the University of Michigan with the degree of bachelor of science in 1926. He was employed as design engineer for the Harkness Laboratories, New York, N. Y., from 1926 to 1928. In 1928 he took charge of the quality division of the superheterodyne division for the RCA Victor Company, Camden, N. J., and in 1931 established M. Kenneth Brody Inc., New York, N. Y., for consulting engineering and the design and manufacture of special testing equipment. Since 1937 he has been technical director of the McCall Test Rooms. Mr. Brody also is a member of the American Society of Refrigerating Engineers.

W. C. White (A '23, M '30) director of the electronics laboratory, General Electric Company, Schenectady, N. Y., has been appointed 1944–45 chairman of the AIEE committee on electronics of which he has been a member since 1942. Mr. White was born March 24, 1890, in Brooklyn, N. Y., and was graduated from Columbia University with the degree of electrical engineer in 1912. He entered the research laboratory of the General Electric Company in 1912 as research assistant and in 1917 was named development engineer. He was placed in charge of the vacuum-tube section of the laboratory in 1927 and of the vacuum-tube engineering department in 1929. When the electronics

A. J. Krupy

M. K. Brody

L. A. Kilgore

laboratory was organized in 1942, he was made director. Mr. White has served on the AIEE committees on electrophysics, 1931–33 and on communication 1935–44. He is the author of several technical articles and has a number of patented inventions in the vacuum-tube field to his credit. He is a member of the Institute of Radio Engineers, Tau Beta Pi, and Sigma Xi.

H. C. Griffith (M '35) electrical engineer, motive power department, Pennsylvania Railroad Company, Philadelphia, has been appointed 1944–45 chairman of the AIEE committee on land transportation of which he has been a member since 1941. Mr. Griffith, who was born June 17, 1890, in New Enterprise, Pa., received the degree of electrical engineer from Lehigh University in 1914. After completing an apprentice course at the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., in 1914, he joined the Pennsylvania Railroad Company in 1915 as draftsman. He was made electrician in 1916, inspector in 1917, and foreman of substation and transmission in 1919. In 1923 he was superintendent of construction for Gibbs and Hill, Philadelphia, and in 1924 returned to the Pennsylvania Railroad as foreman. He became assistant engineer in 1927, assistant electrical engineer in 1929, and electrical engineer in 1935.

J. A. Elzi (A '37, M '38) engineering department, Commonwealth and Southern Corporation, Jackson, Mich., has been appointed 1944–45 chairman of the AIEE committee on automatic stations of which he has been a member since 1941. Mr. Elzi was born September 14, 1896, in Boulder, Colo., and was graduated from the University of Colorado with the degree of bachelor of science in electrical engineering in 1918. In 1919 he entered the employ of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., completed its graduate student course, and worked on d-c railway motor design. From 1921 to 1924 he was instructor in vocational training at the University of Colorado, Boulder, and in 1924 returned to the Westinghouse Company as a d-c motor designer. Since 1926 he has been employed by the Commonwealth and Southern Corporation as substation designer, application engineer, and as engineer in charge of the relaying section. At present he is in charge of system protection studies and equipment application.

A. J. Krupy (A '26, M '33) senior engineer, system-planning division, Commonwealth Edison Company, Chicago, Ill., has been appointed 1944–45 chairman of the AIEE committee on power generation of which he has been a member since 1939. Mr. Krupy was born October 18, 1894, in Orenburg, Russia, studied at the Polytechnic Institute of St. Petersburg, graduated from Massachusetts Institute of Technology with the degree of bachelor of science in 1924, and received the degree of master of science in 1925. He was naturalized in the United States in 1929. During World War I he served as radio operator on Russian icebreakers. He was assistant engineer in the street department of the Commonwealth Edison Company in 1925 and was transferred to the inside-plant division for special studies in 1928. In 1931 he was assigned to the office of the electrical engineer and in 1932 to the system development division of the engineering department as planning engineer, becoming staff engineer in 1942. In 1944 he was made senior engineer. He served as Section secretary in 1937 and 1938 and as Section chairman from 1939 to 1942.

H. E. Strang (A '28, M '39) assistant to vice-president, apparatus design engineering, General Electric Company, Schenectady, N. Y., has been appointed 1944–45 chairman of the AIEE committee on protective devices of which he has been a member since 1940. Mr. Strang, who was born in Mechanicville, N. Y., in 1901, received the degree of electrical engineer from Rensselaer Polytechnic Institute in 1922 and thereupon was employed in the testing department of the General Electric Company, Schenectady, N. Y. He was transferred to the switchboard engineering department in 1924 and to Philadelphia, Pa., to take charge of design of large oil circuit breakers in 1929. In 1931 he was given additional charge of their manufacture. He was appointed engineer of the Philadelphia works in 1940 and assistant to the vice-president in 1944. Mr. Strang served as chairman of the Philadelphia Section of AIEE in 1943 and 1944.

H. W. Bibber (A '21, M '30) professor of electrical engineering and head of engineering department, Union College, Schenectady, N. Y., has been appointed 1944–45 chairman of the AIEE committee on education of which he has been a member since 1937. Professor Bibber was born March 1, 1899, in Gloucester, Mass., and received his degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1920. He studied further at the École Supérieure d'Electricité, Paris, and at the University of Bescanon in 1921 and at the college of business administration of Boston University in 1922. He was exchange instructor to the École Centrale des Arts et Manufactures, Paris, France, in 1920 and 1921, and instructor at Massachusetts Institute of Technology, Cambridge, from 1921 to 1923. He was employed by the International General Electric Company in Tokyo and Osaka, Japan, from 1923 to 1927, and in Schenectady, N. Y., from 1927 to 1931, first in the training course and thereafter in the central-station engineering department. In 1932 he was appointed to the staff of Ohio State University, Columbus, as professor of electrical engineering, and in 1942 received the appointment of professor of electrical engineering and head of the engineering department at Union College. Since 1932 he has acted in a consulting capacity for several firms. Professor Bibber served as chairman of the Columbus Section for 1938–40 and as counselor to the Union College Branch for 1942–44. His committee memberships include: power transmission and distribution, 1932–33, and Student Branches, 1939–43 (chairman 1940–42). He is the author of a number of books, a member of the Society for the Promotion of Engineering Education, Société Française des Electriciens, Tau Beta Pi, Sigma Xi, Eta Kappa Nu, the National Society of Professional Engineers, the American Association of University Professors, the Academy of Political Science, and has served on the American Council of the Institute of Pacific Relations.

W. R. Smith (M '18, F '30) safety engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed 1944–45 chairman of the AIEE finance committee of which he has been a member since 1942. He was born in Charleston, S. C., February 23, 1885, and was graduated from Clemson Agricultural and Mechanical College in 1906 with the degree of bachelor of science in electrical engineering, receiving the degree of electrical engineer in 1928. During 1907 he was employed as secretary and assistant to the head of the engineering department at Clemson College and in 1908 entered the employ of the Hartford Suspension Company, Jersey City, N. J., as draftsman. He became manager of the company's New England office, Boston, Mass., in 1909, of its Newark office in 1911, and was placed in

W. R. Smith

H. C. Griffith

H. W. Bibber

H. E. Strang

charge of the department of design in Jersey City in 1912. During 1913 he was salesman for the White Motor Car Company, Newark. His association with the Public Service Company commenced in 1914 in the electrical construction department, and from 1917 to 1922 he was field engineer in charge of construction work. With the formation of the Public Service Production Company, Newark, in 1922 he became superintendent of electrical construction and in 1924 was appointed managing electrical engineer. In 1927 he was made assistant chief engineer and as such also was employed by the Newark branch of the United Engineers and Constructors, Inc., from 1928 to 1935. In 1936 he returned, as transmission construction engineer, to the Public Service Electric and Gas Company. Since 1938 he has been safety engineer. Mr. Smith is currently (1942–46) serving as a director of the Institute. He has been active on the following committees: publications, 1935–36; coordination of Institute activities, 1935–37; Alfred Noble Prize, 1936–37; safety, 1939–45 (chairman, 1943–45); board of examiners, 1930–36 (chairman, 1934–36); award of Institute prizes, 1935–37 (chairman, 1935–36). In addition he was chairman of the New York Section for 1934–35, and secretary for 1932–33. He has served on the National Fire Waste Council and on committees of the National Fire Protection Association and holds membership in the National Society of Professional Engineers, the Edison Electric Institute, the American Standards Association, the American Society of Safety Engineers, and the National Safety Council.

J. H. Miller (A '19, F '42) formerly assistant chief electrical engineer, Weston Electrical Instrument Corporation, Newark, N. J., has been promoted to chief electrical engineer. In 1919, following his discharge from the United States Army in which he served as a second lieutenant in the Signal Corps, Mr. Miller joined the Jewell Electrical Instrument Company, Chicago, Ill., as chief engineer and in 1931, after the Jewell Company was merged with Weston Electrical, Mr. Miller became assistant chief engineer for the latter organization. **F. X. Lamb** (A '36) formerly development engineer, has been made assistant chief electrical engineer. Mr. Lamb has been with the Weston Electrical Instrument Corporation since 1921.

E. B. Paine (A '04, M '12) professor and head of the department of electrical engineering, University of Illinois, Urbana, Ill., retired on September 1. Professor Paine was graduated from Worcester Polytechnic Institute in 1897 and in 1898 he entered the testing department of the General Electric Company, Schenectady, N. Y. After leaving the General Electric Company, Professor Paine was employed by the Lehigh Valley Coal Company, Wilkes-Barre, Pa., from 1899 to 1902. The remainder of his career has been spent in electrical engineering research and teaching at Stetson University, De Sand, Fla., North Carolina State College, Raleigh, N. C., and at the University of Illinois where he has been on the staff since 1907.

C. E. Torrey (A '05) vice-president and general manager of the Ohio Power Company, Canton, has retired. Mr. Torrey began his work in electric utilities in 1899 when he became superintendent of water and lights for the Lake Superior Power Company, Sault Sainte Marie, Ontario, Canada. In 1910 he was an assistant manager at the Janesville (Wis.) Electric Company, and in 1911 joined the Canton (Ohio) Electric Company, which later became part of the Ohio Power Company. Mr. Torrey was appointed as general manager in 1923 and was elected vice-president in 1942. He will continue to serve the company in a consulting capacity.

F. D. Weber (A '09, M '30) chief electrical engineer of the Oregon Insurance Rating Bureau, Portland, retired on May 15. Mr. Weber was graduated from the University of California in 1904 with a bachelor of science degree and in 1906 he completed an engineering apprenticeship course at Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He began his professional career in 1906 as a salesman for the Allis-Chalmers Manufacturing Company, Cincinnati, Ohio, and in 1907 became chief electrical engineer for the Oregon Insurance Rating Bureau.

D. C. Ober (A '16) formerly an electrical engineer for the Cleveland (Ohio) Electric Illuminating Company, has been elected a vice-president. In 1913, after his graduation from the Case School of Applied Science with a bachelor of science degree in electrical engineering, Mr. Ober was employed by the Cleveland Electric Illuminating Company in electrolysis investigation. In 1913 he joined the staff of the University of Akron as a teacher of mathematics, physics, and electrical subjects, and in 1914 he returned to the Cleveland Electric Illuminating Company.

R. H. Olson (A '21) formerly eastern sales manager of the Electric Machinery Manufacturing Company, Minneapolis, Minn., has been appointed vice-president in charge of sales. Mr. Olson joined the Electric Machinery Manufacturing Company in 1919 as a tester and later became an erecting engineer. In 1920 Mr. Olson became partner in the firm of Pearson and Olson, service engineers, Chicago, Ill., but returned to the Electric Machinery Company in 1924 as district sales manager at St. Louis, Mo. He was transferred to New York about 1929.

R. G. Walter (M '21) assistant to the executive vice-president of the Wisconsin Power and Light Company, Madison, has been elected vice-president in charge of operations. A graduate of the University of Wisconsin in 1905, he joined the Wisconsin Power and Light Company in 1919 as assistant general superintendent. He subsequently held the position of assistant general superintendent, general superintendent, and division manager, and since 1933 he has been assistant to the executive vice-president.

F. C. Angle (A '38) manager of sales in the Pacific region for the Allis-Chalmers Manufacturing Company, has been appointed manager of all its field sales offices of the general machinery division. A graduate of Oregon State College in 1923 with a bachelor of science degree, Mr. Angle joined the Allis-Chalmers Company in 1929. In 1935 he became manager of the San Francisco, Calif., office and in 1943 he was appointed manager of the Pacific region.

W. S. Eldredge (A '20, M '27) assistant chief testing engineer for the Commonwealth Edison Company, Chicago, Ill., has retired. Mr. Eldredge attended the Lewis Institute of Technology until 1910 when he began work at the Commonwealth Edison Company in the testing department after a year as operator for the City of Chicago. In 1919 Mr. Eldredge was made testing engineer in charge of generating stations, and in 1938 he became assistant chief testing engineer.

J. C. Burkholder (M '30) formerly vice-president of Burlec, Ltd., Toronto, Ontario, Canada, has resigned from the Burlec Company and will direct Cyclograph Services, Ltd., Toronto. In 1927 Mr. Burkholder made a complete survey of the transcontinental telegraph lines of the Canadian National Railway as consulting expert and in 1928 he was made chief engineer of that company's telegraph system. He became vice-president of Burlec, Ltd., in 1935.

R. J. Carlson (Student Member) a private in the United States Infantry, has been awarded the District 6 prize for Branch paper as co-author of the paper, "A Two-Speed A-C Generator." Private Carlson was born on July 22, 1920, in Denver, Colo. He was graduated from the University of Denver in 1944 with a bachelor of science degree and was inducted into the Army in July. He is now stationed at Camp J. L. Robinson, Ark.

K. R. Van Tassell (A '27) formerly manager of sales of the motor section, motor division of the General Electric Company, Schenectady, N. Y., has been named manager of the industrial-control division of the General Electric Company's industrial divisions. Mr. Van Tassell has been associated with the company since his graduation from Massachusetts Institute of Technology in 1925.

W. P. Cochran (A '25) manager of the central-station division, Westinghouse Electric and Manufacturing Company, Philadelphia, Pa., retired recently. Mr. Cochran was graduated from Pennsylvania State College in 1898. He has been associated with the Westinghouse Company since 1905, with the exception of an interval of two years during which time he was in business for himself.

C. P. West (A '20, M '28) formerly section engineer, switchboard-engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. has been appointed manager of switchboard engineering. He joined the switchboard division of the Westinghouse Company in 1926. Since 1927 he has been a section engineer.

F. R. George (A '13, M '25) engineer of electrical operation, Pacific Gas and Electric Company, San Francisco, Calif., has been appointed superintendent of the northern area of the company's territory. **D. D. Smalley** (A '20, M '33) formerly general superintendent of the San Joaquin Power division of the company has been appointed superintendent of the central area.

M. H. Hobbs (M '37) formerly manager of switchboard engineering, Westinghouse Electric and Manufacturing Company, East

Pittsburgh, Pa., has been appointed manager of the engineering department of the switchgear and control division. Mr. Hobbs has been with the Westinghouse Electric and Manufacturing Company since 1922.

H. L. Buck (A '35) formerly sales engineer, I-T-E Circuit Breaker Company, Philadelphia, Pa., has been appointed assistant to the president. After his graduation from Drexel Institute in 1934, he was employed by Day and Zimmerman, Philadelphia, Pa., and in 1935 Mr. Buck joined the I-T-E company as a member of the sales department.

R. H. Smith (M '36) manager of the application engineering department of the Reliance Electric and Engineering Company, Cleveland, Ohio, has been named head of the company's sales promotion department. **W. C. Madsen** (A '42) application engineer, has been appointed assistant to the manager of applied engineering.

J. B. MacNeill (A '18, F '42) formerly manager of engineering, switchgear division, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed manager of the switchgear and control division. A biography of Mr. MacNeill appeared in *Electrical Engineering*, November 1943, page 504.

J. K. Bradford (A '33), lieutenant colonel in the Canadian Army, formerly associated with the Canadian Wire and Cable Company, Ltd., Toronto, Ontario, Canada, has been awarded the Order of the British Empire. Colonel Bradford was with the 1st Canadian Division in Sicily and later commanded the ordnance section in Italy.

J. J. Kane (M '15) formerly patent attorney, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has been appointed general patent attorney. From 1906 to 1912 Mr. Kane was employed as assistant examiner in the United States Patent Office, Washington, D. C. He has been with the Allis-Chalmers Company since 1912.

T. M. Foulk (A '43) superintendent of the appliance service department of the Public Service Company of Colorado, Denver, has been appointed chairman of the postwar promotional and development committee of the wiring bureau of the Rocky Mountain Electrical League.

J. S. Mahan (A '12, F '27) consultant of Chicago, Ill., has been appointed special consultant for the Ceramics Specialities Company, the Illinois Electric Porcelain Company, Porcelain Products, Inc., Specialty Works, the Superior Porcelain Company, and the Universal Clay Products Company.

H. D. Moreland (A '35, M '41) formerly manager of the X-ray products agencies and specialties department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been transferred to Baltimore, Md., as manager of the engineering department of the X-ray products plant.

W. C. Walsh (A '43) formerly with the United States Farm Security Administration, San Francisco, Calif., as electrical design engineer, has been appointed district representative for the electronics department, General Electric Company, San Francisco, Calif.

Paul Augustine (A '17) formerly teacher in charge of the main building of the Manhattan High School of Aviation Trades, New York, N. Y., has retired. Since 1934, Mr. Augustine has held the positions of teacher, administrative assistant, acting principal, and teacher in charge in that school.

E. W. Starr (A '28, M '36) formerly assistant professor of electrical engineering, Cooper Union, New York, N. Y., has been made associate professor. Professor Starr has been a member of the faculty of Cooper Union since 1931 and an assistant professor since 1935.

R. I. Hanford (M '42) formerly assistant chief engineer, Ilg Electric Ventilating Company, Chicago, Ill., has been given the title of electrical engineer. Mr. Hanford has been employed by the company since 1914 and has specialized in electric motor development.

S. M. Johns (A '42) formerly sales engineer, Westinghouse Electric and Manufacturing Company, Salt Lake City, Utah, has been named manager of the Company's Salt Lake City office. Mr. Johns joined the Westinghouse Company as a graduate student in 1926.

F. B. Viller (A '40) maintenance engineer for the operating department, San Joaquin power division, Pacific Gas and Electric Company, Fresno, Calif., has resigned to become Western division engineer with the Gould Storage Battery Company.

E. A. Roberts (A '17, M '20) formerly associate director, division of local transport, Office of Defense Transportation, Washington, D. C., has been appointed director, passenger-operations division, highway transport department of the same agency.

A.P.T. Sah (A '35, M '36) president, National University of Amoy, Changting, Fukien, China, has been appointed representative of the university in the United States for one year, at the invitation of the United States Department of State.

F. H. McIntosh (M '37) formerly assistant director and chief of the domestic and foreign branches, radio division, War Production Board, Washington, D. C., has resigned his position. He is opening Washington offices as an industry consultant.

C. W. La Pierre (A '28, M '43) formerly development engineer, General Electric Company, Schenectady, N. Y., has been appointed assistant engineer. He has been associated with the General Electric Company since 1924.

J. S. Henderson (A '04, M '13) central-station department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed co-ordinator of rural electrification for the industry departments.

C. G. Howard (A '28, M '36) formerly assistant general sales manager, Fansteel Metallurgical Corporation, North Chicago, Ill., has resigned to open his own firm as a manufacturer's representative.

R. L. Lloyd (A '37) associate electrical engineer, National Bureau of Standards, Washington, D. C., has been made chairman of the national electrical code regulations to apply to prefabricated houses.

J. S. Murray (A '21, M '31) chief electrical engineer, Follansbee (W. Va.) Steel Corporation, has been appointed a member of the American Iron and Steel Institute subcommittee on electrical steel sheets.

H. L. Logan (A '19, F '43) postwar planning consultant, Holophane Company, Inc., New York, N. Y., has been elected an honorary life member of the National Institute of Illumination of Mexico.

OBITUARY • • • •

John A. Peterson (A '37) engineer, Willow Run (Mich.) bomber plant of the Ford Motor Company, died July 13, 1944. Mr. Peterson was born August 8, 1897, in Manistee, Mich. He was a veteran of World War I and was graduated from the University of Michigan with the degree of bachelor of science in electrical engineering in 1923. He was employed by the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., until 1924 when he joined the Commonwealth Power Corporation, Stevens and Wood, Inc., and Allied Engineers, Inc., Jackson, Mich. From 1932 to 1936 he was employed at the State Prison of Southern Michigan as an electrical engineer. In 1936 he became associated with the Commonwealth and Southern Corporation at Jackson. Mr. Peterson joined the Ford Motor Company in 1943.

Herbert Earnest Fuqua (A '42) marine and aeronautical engineer, General Electric Company, Los Angeles, Calif., died February 23, 1944. Mr. Fuqua was born April 19, 1885, in Terre Haute, Ind. He was graduated from the Stanford University with the degree of bachelor of arts in 1909 and received the degree of mechanical engineer in 1910. Mr. Fuqua was employed by the Southern California Edison Company, Ltd., Los Angeles, from 1911 to 1917. He had been associated with the General Electric Company, Los Angeles, since 1917.

Harry C. Turnock (A '16, M '28) major, United States Army Reserve Corps, and chief electrical engineer, J. Gordon Trumbull, Inc., Edmonton, Alberta, Canada, died June 4, 1944. Major Turnock, who was born April 17, 1881, in Elkhart, Ind., attended the University of Illinois. He enlisted in the United States Navy in 1899 and served as chief electrician until 1903. From 1903 to 1908 he engaged in the electrical contracting business. He was employed by the Cleveland (Ohio) Electric Illuminating Company, central station, from 1908 to 1912. In 1912 he became president and general manager of the Electric Construction and Sales Company, Cleveland, and remained there until he was commissioned first lieutenant in the United States Army, in 1917. He served in the American Expeditionary Force as radio instructor and, later, as regimental communication officer, and was promoted to a captaincy. In 1919 and 1920 he was electrical engineer with the United Electric Construction Company, Cleveland. He was employed as engineer by the Hatfield Electric Company, Cleve-

land, in 1921. In 1928 he was made chief electrical engineer of the company, and in 1937 he became vice-president. Major Turnock joined J. Gordon Trumbull, Inc., in 1942 when the firm was commissioned to supervise the Canol project, developed by the Army to utilize the supply of petroleum discovered in Alaska. He was in charge of all telephones and wiring for the project.

Loyall Allen Osborne (A '93, M '12, F '12) formerly vice-president, Westinghouse Electric and Manufacturing Company, New York, N. Y., died August 18, 1944. Mr. Osborne was born in Newark, N. J., June 22, 1870, and in 1891 was graduated from Cornell University. In the same year, he went to work in the Newark plant of the Westinghouse Company as a designer and also was put in charge of engineering and testing. He was transferred to the East Pittsburgh plant as assistant superintendent in the manufacturing department in 1895, in 1897 was appointed assistant to the vice-president, and in 1899 was made manager of works. Mr. Osborne became vice-president in charge of manufacturing and engineering in 1902 and vice-president in charge of commercial operations in 1906. In 1915 he was sent to New York to handle the company's general commercial and foreign policy, and, when the Westinghouse Electric International Company was formed, he was elected its president. He was made a director of the Westinghouse Electric and Manufacturing Company in 1924 and in 1936 retired from active business. Mr. Osborne was a member of the American Society of Mechanical Engineers, the American Association for the Advancement of Science, the Society for the Promotion of Engineering Education, the American Electrochemical Society, and the Franklin Institute.

Arthur Coy Woodward (A '18) Visalia, Calif., died July 17, 1944. Born in Greensburg, Ind., August 18, 1890, he was graduated from DePauw University with a bachelor of arts degree in 1913. He was employed as a bookkeeper in the Citizens National Bank, Greensburg, until 1914 and during the summer of 1916 he did electrical test work for the Allis-Chalmers Manufacturing Company, Norwood, Ohio. After his graduation from Cornell University with an engineering degree in 1917, he joined the engineering department of the Chesapeake and Potomac Telephone Company, Baltimore, Md., but left in 1920 to become an engineer in the B. F. Goodrich Rubber Company, Akron, Ohio. The following year he was appointed chief electrical inspector for the City of Akron. In 1924 Mr. Woodward became manager of the Decatur County Independent Telephone Company, Greensburg, and in 1928 was employed as an engineer in the Home Telephone and Telegraph Company, Fort Wayne, Ind. He moved to California in 1934 where he operated "coin-operated machine" routes in the San Joaquin Valley and in the vicinity of Santa Maria, Calif.

Stuart Ballantine (M '42) president, Ballantine Laboratories, Inc., Boonton, N. J., died recently. Born in Germantown, Pa., September 22, 1897, Mr. Ballantine attended Harvard University in 1920 and 1921 and in 1923 and 1924 was a John Tyndall Fellow. He became an expert radio aide in the United States Navy in 1917 and in 1922 was employed as research engineer in the Radio Frequency Laboratories, Inc., Boonton, N. J. In 1927, following three years of private research, he returned to the Radio Frequencies Laboratories as superintendent of the research department. He became president of the Boonton Research Corporation in 1929 and in 1934 president of the Ballantine Laboratories, Inc. Mr. Ballantine was a member of the Institute of Radio Engineers, the American Physical Society, the Acoustical Society of America, and the Franklin Institute. In 1931 he received the Liebmann medal awarded by the Institute of Radio Engineers and in 1934 he was awarded the Franklin Institute's Elliott Cresson medal. He was the author of many technical papers, and a number of patents have been issued in his name.

Robert Conrad Skone (A '19, M '37) senior engineer, Light Department of the City of Seattle, Washington, died August 14, 1944. Mr. Skone was born in Carver, Minn., May 3, 1887, and was graduated from the University of Washington in 1909 with the degree of bachelor of science in electrical engineering. For four months after his graduation he worked for the Seattle-Tacoma Power and Light Company and then entered the employ of the Seattle Light Department as a journeyman electrician. In 1918, after work on the city's Skagit Hydro and Cedar Falls projects, he became foreman of inside construction in charge of maintenance and incidental construction of the department's power-generating station. In 1920 Mr. Skone superintended the installation of machinery on the Cedar Falls project and in 1922 he returned to his former position as foreman of maintenance and construction. In 1934 he served as resident engineer at the Diablo power house and in 1936 was resident engineer in charge of power stations. He became senior engineer in 1942.

Evans H. Cox (A '41) manager, manufacturing and repair, Westinghouse Electric and Manufacturing Company, Charlotte, N. C., died July 6, 1944. He was born in Charlotte, N. C., on May 24, 1891. In 1909 he entered the employ of the Southern Bell Telephone Company, Charlotte, and from 1910 to 1922 his career covered positions with the Charlotte Electric Repair Company, the Carolina Electric Works, Greensboro, the Huntington-Gurry Electric Company, Greenville, S. C., the Boroughs Electric Company, Greenville, and the Jones Electric Company, Charlotte. Mr. Cox joined the Westinghouse Electric and Manufacturing Company, St. Louis, Mo., in 1922 as an armature winder and general repair and trouble man. In 1924 he was transferred to the Kansas City service as shop foreman and in 1930 became manager. He was sent to Denver, Colo., as manager in 1935, and in 1942 he was transferred to Charlotte.

Donald A. Pierce (A '21, M '32) engineer, inductive co-ordination, Public Service Company of Northern Illinois, Chicago, died June 28, 1944. Mr. Pierce was born in Martinton, Illinois, November 20, 1883, and received his bachelor of science degree in electrical engineering from the University of Illinois in 1910. After graduation he became assistant to the district inspector, North Shore Electric Company, Evanston, Ill. In 1911 he was district inspector for the Public Service Company of Northern Illinois at Waukegan and in 1913 was transferred to Evanston. In 1914 and 1915 he was inventory supervisor of several of the company's districts and in 1915 became district engineer at Joliet. In 1920 Mr. Pierce was made engineer of electrical distribution, and he was appointed engineer of inductive co-ordination in 1930.

Allen T. Sinks (A '36, M '42) designing engineer, instrument transformer engineering department, General Electric Company, Lynn, Mass., died August 3, 1944. Born June 21, 1907, in Columbus, Ohio, Mr. Sinks was graduated from Yale University in 1929 with a bachelor of science degree in electrical engineering. In 1929 he took the advanced engineering course at the General Electric Company, Schenectady, N. Y., and in 1930 was transferred to the Lynn plant where he was employed in the development and design of dry-type instrument transformers. Since 1942 he had been engaged in confidential work on war products. Mr. Sinks was a member of the West Lynn Engineering Association, Tau Beta Pi, and Sigma Xi, and author of several technical papers.

David L. Lewis (A '25) electrical engineer, operating department, Georgia Power Company, Atlanta, died July 28, 1944. He was born on January 21, 1900, in Melbourne, Australia, and was educated at Xavier College and the University of Melbourne. In 1921 he was employed in the workshop of the English Electric Company of Australia and in 1923 went to work for the Melbourne Electric Supply Company. Mr. Lewis came to the United States in 1925 and took a position as design engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1928 he resigned to become electrical engineer for the Georgia Power Company.

R. Denton Karle (A '40) formerly electrical engineer, American Telephone and Telegraph Company, Chicago, Ill., died July 27, 1944. Mr. Karle was born on June 27, 1903, in Wilderville, Mich. His association with the American Telephone and Telegraph Company began in 1926 when he was employed as a tranamission engineer. From 1931 until 1939 he was with the company in an administrative capacity connected with the development and operation of a new type of communication service, and in 1939 he was made an equipment engineer. Mr. Karle recently had returned from Alaska where he was in charge of important defense work.

John T. Binford (A '23) telephone engineer, American Telephone and Telegraph Company, New York, N. Y., died July 10, 1944. Mr. Binford was born in Maryland on June 27, 1894. In 1921 he entered the engineer-

ing department of the Chesapeake and Potomac Telephone Company, Washington, D. C., as an assistant. He was employed as a telephone engineer for the American Telephone and Telegraph Company since 1926.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on September 21, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Borden, P. A., patent engr., The Bristol Co., Waterbury, Conn.
Brackett, H. H., engr. of toll plant extension & transmission, New Jersey Bell Tel. Co., Newark, N. J.
Bramhall, F. B., transmission research engr., Western Union Telegraph Co., New York
Coleman, O. K., asst. to vice-president & chief engr., American Gas & Elec. Service Corp., New York
Hanna, C. R., mgr., Electro-Mechanical Dept., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Hockaday, O. S., supt. of transmission, Texas Electric Service Co., Ft. Worth, Texas
Kerr, H. H., general supt., Toledo Edison Co., Toledo, Ohio
Leland, G. H., development engr., G. H. Leland Development Engg. Co., Dayton, Ohio
Murray, W. A., head, dept. of elec. engg., Virginia Polytechnic Institute, Blacksburg, Va.
Porter, R. G., prof. and head of dept. of elec. engg., Northeastern University, Boston, Mass.
Schwager, A. C., chief engr. and vice-president in charge of engg., Pacific Electric Mfg. Corp., San Francisco, Calif.
Smith, H. K., Northeastern engg. and service mgr., Westinghouse E. & M. Co., Chicago, Ill.

12 to grade of Fellow

To Grade of Member

Allard, E. P., elec. engr., Howard P. Foley Co., Washington, D. C.
Anderson, F. A., elec. engr., E. I. duPont de Nemours & Co., Niagara Falls, N. Y.
Barry, J. C., engg. asst., Ohio Public Service Co., Ashland, Ohio
Blincoe, L. R., sales engr., General Elec. Co., Newark, N. J.
Boeworth, P. N., elec. engr., General Elec. Co., Pittsfield, Mass.
Brainard, M. W., experimental engr., O'Keefe & Merritt Co., Los Angeles, Calif.
Brumbaugh, K. D., head of elec. engg. section NACA., Cleveland Airport, Cleveland, Ohio
Case, B. A., administrative engr., General Elec. Co., Fort Wayne, Ind.
Clarke, P. G., asst. general mgr., Hunter Pressed Steel Co., Landale, Pa.
Colby, F. S., elec. engr., Ebasco Services, Inc., New York
Donaldson, R. J., engr., Commonwealth Edison Co., Chicago, Ill.
Doyle, A. M., mgr., transformer sales, Canadian General Elec. Co., Toronto, Ont., Canada
Falconer, M. C., supervisor of elec. design, 13th Naval Dist., Seattle, Wash.
Falls, H. H., laboratory engr., General Elec. Co., Lynn, Mass.
Ford, P. C., elec. engr., Wagner Elec. Corp., St. Louis, Mo.
Germeck, C. W., measurements lab. section head, General Elec. Co., Pittsfield, Mass.
Gioberti, P. A., senior draftsman, George G. Sharp, New York
Harris, W. R., industry engr., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Hervey, W. K., design engr., Commonwealth Edison Co., Chicago, Ill.
Howe, C. D., protection engr., Pacific Tel. & Tel. Co., Seattle, Wash.
Janz, W. F., starting engr., Northern Indiana Public Service Co., Hammond, Ind.
Johnson, E. A., chief engr., Southern New England Tel. Co., New Haven, Conn.
Johnson, J. K., executive engr., Hammerlund Mfg. Co., Inc., New York
Kendall, O. K., elec. engr., National Film Board, Ottawa, Ont., Can.
Kirby, M. W., elec. engr., Bureau of Ordnance, Navy Dept., Washington, D. C.
Lamb, A. H., chief relay engg. div., Weston Electrical Instrument Corp., Newark, N. J.
Lockwood, E. S., division supt., Public Service Elec. & Gas Co., Jersey City, N. J.
Lotz, E. L., research director, New Jersey Wood Finishing Co., Woodbridge, N. J.
Maust, C. L., electric job engr., Ebasco Services, Inc., New York
Maxanec, W., elec. engr., Rural Electrification Admn., St. Louis, Mo.
Moses, G. I., engr.-in-charge, insulation, development group, Westinghouse E. & M. Co., E. Pittsburgh, Pa.

31 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the national secretary before October 31, 1944, or December 30, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Balint, A. T., National Mineral Co., Chicago, Ill.
Bellis, W. H. A., Westmoriand & Dist. Elect. Sup. Co., Ltd., Appleby, England
Betz, N. J., B. & O. R.R. Co., Baltimore, Md.
Cass, F. W., Stone & Webster Engg. Corp., Knoxville, Tenn.
Corbett, C. W., Western Elec. Co., Kearsay, N. J.
Everitt, L. H. R., Royal Aircraft Establishment, Farnborough, England
Gafford, B. N. (Reelection), Univ. of Texas, Austin, Texas
Gillings, H., Basic Magnesium Co., Henderson, Nev.
Hanzlik, J. R., W. H. M. S. Co., Phoenix, Ariz.
Holley, B. D. (Reelection), Commonwealth Edison Co., Chicago, Ill.
Jennings, H. S., Bechtel Price Callahan, Edmonton, Alta., Can.
Lubin, S., Harvard Univ., Cambridge, Mass.
Mamarchev, J. D. (Reelection), U. S. Navy Yard, Mare Island, Calif.
Maxwell, W. E., Standard Elec. Time Co., Springfield, Mass.
Miller, R. R., H. A. Brassert & Co., Inc., New York, N. Y.
Parker, A. L., Parker Appl. Co., Cleveland, Ohio
Schuster, H. F. E., Jr., Bell Aircraft Corp., Marietta, Ga.
Sitterley, L. J., N. Y. State Agri. & Tech. Inst., Canton, N. Y.
Spence, S. F. (Reelection), Liberty Mut. Ins. Co., Buffalo, N. Y.
Van Duzer, L. S., New York State Elec. & Gas Corp., Elmira, N. Y.
Webster, S. H., Eclipse Pioneer Div., Los Angeles, Calif.
Wilder, V. E., U. S. Rubber Co., Ankeny, Iowa
Wilson, D. G., Consolidated-Vultee Aircraft Corp., San Diego, Calif.
Zelikin, B. D., Palestine Elec. Corp. Ltd., Tel-Aviv, Palestine

24 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Byrd, D. L., U.S.M.S., Fort Trumbull, Conn.
Heumann, G. W., Gen. Elec. Co., Schenectady, N. Y.
Knight, E. W. (Reelection), Westinghouse Elec. & Mfg. Co., Boston, Mass.
Krouse, W. C., Lieut. (jg), U.S.M.S., New London, Conn.
Smalto, F. J., Anchor Mfg. Co., Manchester, N. H.
Steele, R. W., Cornell Univ., Ithaca, N. Y.
Swinney, J. G. C., Jr., Harvard Univ., Cambridge, Mass.
Thomas, C. R., Gen. Elec. Co., Pittsfield, Mass.
Toomey, J. R., Blackstone Valley Gas & Elec. Co., Pascoag, R. I.
Walker, R. H., Holyoke Water Pr. Co., Holyoke, Mass.
Walter, G. E., Gen. Elec. Co., Schenectady, N. Y.

2. MIDDLE EASTERN

Andrews, A. W., Cons. Gas Elec. Lt. & Pr. Co., Baltimore, Md.
Bailey, T. G., Lieut., U.S.N.R., 635 S. Roosevelt Ave., Piqua, Ohio
Campbell, F. W., Naval Ord. Lab., Washington, D. C.
Fredericks, R. M., Cons. Gas Elec. Lt. & Pr. Co., Baltimore, Md.
Gibson, W. H., Master Elec. Co., Dayton, Ohio
Grierson, J. H., Jr., U. S. Naval Acad., Annapolis, Md.
Hoffmann, J. T. (Reelection), Kwis, Hudson, Boughton, & Williams, Cleveland, Ohio
Horton, G. A., U.S.A.A.F., Wright Field, Dayton, Ohio
Hubacher, E. J., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Izzo, A., West Penn Pr. Co., Pittsburgh, Pa.
Leimkuhler, E. J., Cons. Gas Elec. Lt. & Pr. Co., Baltimore, Md.
Mallon, M. J., Lieut. (jg), U.S.N.R., Patuxent River, Md.
Marshall, T. H., Jr., Gen. Elec. Co., Baltimore, Md.
McIntyre, J. A., Westinghouse Elec. & Mfg. Co., Baltimore, Md.
Meck, H., Jr., Dravo Corp., Wilmington, Del.
Phillips, R. J. (Reelection), Scranton Elec. Co., Scranton, Pa.
Richenbour, W. L. (Reelection), Penna. Water & Pr. Co., Baltimore, Md.
Roeding, F. C., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Shaffer, J. G., Atlantic Ref. Co., Philadelphia, Pa.
Silling, G. M., Line Material Co., Zanesville, Ohio
Smith, L. L., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Talbot, F. L., Capital Transit Co., Washington, D. C.
Waltz, R. E., Baltimore Transit Co., Baltimore, Md.

3. NEW YORK CITY

Adams, G. R., Sperry Gyroscope Co., Brooklyn, N. Y.
Anderson, S., James Stewart & Co., Inc., New York, N. Y.
Billman, E. F., Bell Tel. Labs., Murray Hill, N. J.
Cross, G. W., Gen. Elec. Co., New York, N. Y.
Heidrich, R. H., Wallace & Tiernan Co., Inc., Newark, N. J.
Peters, J. S., N. J. Bell Tel. Co., Newark, N. J.
Smith, T. R., Westinghouse Elec. & Mfg. Co., Newark, N. J.
Widmer, A. E., Anaconda Wire & Cable Co., Hastings-on-Hudson, N. Y.

4. SOUTHERN

Blum, L. L., Higgins Ind., Inc., New Orleans, La.
Burdsal, A. J., Southern Bell Tel. & Tel. Co., Jackson, Miss.
Darlington, B. N., Peninsular Tel. Co., Tampa, Fla.
Kimrey, J. O., Duke Pr. Co., Durham, N. C.
Leslie, F. H., Tenn. Valley Auth., Chattanooga, Tenn.
Miller, J. R., Jr., Tenn. Val. Auth., Chattanooga, Tenn.
Saunders, A. B., Higgins Ind., Inc., New Orleans, La.
Smith, C. D., Higgins Industries, Inc., New Orleans, La.
Wright, H. M., U.S.N., Pascagoula, Miss.

5. GREAT LAKES

Barr, N. K. (Reelection), Pub. Serv. Co. of Northern Ill., Chicago, Ill.
Bartucci, J. V., Public Utility Engg. & Serv. Corp., Chicago, Ill.
Clayton, J. T., Power Equipment Co., Detroit, Mich.
Hill S., F. A., U. S. Rubber Co., Mishawaka, Ind.
Hure, L. J., Pub. Serv. Co. of Northern Ill., Evanston, Ill.
Mitchell, F. T., Ill. Pr. Co., Granite City, Ill.
Reber, G., Stewart Warner Corp., Chicago, Ill.
Speight, W. D., Caterpillar Tractor Co., Peoria, Ill.
Switzer, G. F., Indianapolis Pr. & Lt. Co., Indianapolis, Ind.
Tometz, M. G., Minn. Min. & Mfg. Co., St. Paul, Minn.

6. NORTH CENTRAL

Christensen, R. S., U. S. Bureau of Reclamation, Denver, Colo.
Steuart, G. B., Pub. Serv. Co. of Colo., Denver, Colo.

7. SOUTH WEST

Bost, W. A. (Reelection), Pine Bluff Arsenal, Pine Bluff, Ark.
Knight, A. G., Rural Elect. Adm., St. Louis, Mo.
Marienfeld, L., Brown Shipbuilding Co., Inc., Houston, Texas
O'Connor, R. A., U.S.A. Air Corps, Biggs Field, Texas
Schreiner, W. H., Rural Elect. Adm., St. Louis, Mo.
Squires, W. G., North Amer. Avia. Co., Dallas, Texas

8. PACIFIC

Anglemyer, W. J. (Reelection), Douglas Aircraft Co., Santa Monica, Calif.
Cripps, R. H., Sawyer Elec. Mfg. Co., Los Angeles, Calif.
Defibaugh, E. M., North Amer. Avia., Inc., Inglewood, Calif.
Mitchell, C. W., U. S. Navy Yard, Mare Island, Calif.
Monell, L. E., North Amer. Avia., Inc., Inglewood, Calif.
Rogness, E. C., San Diego Gas & Elec. Co., San Diego, Calif.
Sawyer, M. B., Jr., Sawyer Elect. Mfg. Co., Los Angeles, Calif.
Winchester, R. E., U. S. Navy Yard, Mare Island, Calif.

9. NORTH WEST

Van Ness, E. E., Parker & Hill Assoc., Seattle, Wash.

10. CANADA

Galer, F. C. (Reelection), Bedard-Girard Ltd., Montreal, Que., Can.
Malkin, A. (Reelection), Can. Car & Fdry. Co., Ltd., Montreal, Que., Can.
Mann, D. E., Ford Motor Co. of Can., Windsor, Ont., Can.
Nixon, G. M., Bell Tel. Co. of Can., Toronto, Ont., Can.

Elsewhere

Alatorre, C. P., Cia. West. Elec. Int., Mexico, Mex.
Avila, F. C., General Supply Co., Mexico, Mex.
Aymes, C., A., Electrical Contractor, Mexico, Mex.
Barona, S., F., Electrical Engineer, Mexico, Mex.
Bisso, A. M., Siam Di Tella, Buenos Aires, Arg., S. A.
Castro, M. G., Mexi. Lt. & Pr. Co., Mexico, Mex.
Catalan, G., A., Com. Fed. de Elec., Mexico, Mex.
Domenzain C., S. M., Bucareli 73-C, Mexico, Mex.
Escofet M., A., Suministros Industriales, S. A., Mexico, Mex.
Fregoso V., M. F., Dept. of Ind. Hygiene, Mexico, Mex.
Guzman, B. R., Gen. Sup. Co., Mexico, Mex.
Jimenez D., E. S., CIA Dist. Westinghouse, S. A., Mexico, Mex.
Kerawalla, R. D., Kolster Brandes Ltd., London, England
Kopol, F., Goodmans Industries, Ltd., Wembly, England
Montiel, C., M., Tabasco 45, Mexico, Mex.
Mota, M., E., Mex. Lt. & Pr. Co., Mexico, Mex.
Padilla S., J. A., Cons. Nac. de Irrig., Mexico, Mex.
Perezvaldes A., C., Com. Nac. de Irrig., Mexico, Mex.
Ramirez U., C., LaComision Fed. de Elec., Mexico, Mex.
Ramonedo C., E., Valladolid 25, Mexico, Mex.
Raul G., F., CIA, SKF Golfo y Caribe, S. A., Mexico, Mex.
Rodriguez M., F., Const. Nac. Mexicanas, S. A., Mexico, Mex.
Rohatyn, F., Siam Di Tella, Avellaneda, Arg., S. A.
Romo G., A., Eficiencia Industrial, S. de R. L., Mexico Mex.
Spindola L., M., Mex. Lt. & Pr. Co., Mexico, Mex.
Torres G., R., Torres Garcia y Bustamente, Zamora, Mich., Mex.
Uribe, F., G., Ingenio Cuatotolapam, Veracruz, Mex.
Zolliker, S. J., Com. Nac. de Irrig., Mexico, Mex.

Total to grade of Associate
United States and Canada 82
Elsewhere 28

OF CURRENT INTEREST

Transportable Transformers Prevent British Power Shutdowns

The transportable transformers of various sizes and voltages manufactured through the foresight of the General Electricity Board contributed to the fact that so little disruption of power supply was experienced in England despite frequent bombings. The availability of such transformers resulted in the electricity supply's being reinstated in a very short time after disastrous enemy action, according to the *Electrical Review*, weekly London publication.

These transformers are designed specially so that they can be moved, completely assembled and filled with oil, by road or rail and be ready for service immediately after being connected. Several 10,000-kva and some 7,500-kva transformers of this type also were dispatched to Russia by the English Electric Company, Ltd. The transformers supplied to Russia were provided with three separate windings, each of full transformer capacity for service at 110 kv and 38.5 kv and 6.6 kv and were constructed so that they could be transported on the Soviet railways on existing flat-bottom cars.

Taps, located in the middle of the transformer windings, allow for ±2 per cent and ±5 per cent variation in the normal voltage on both the 110-kv and 38.5-kv windings. These taps are adjusted by means of externally operated switches. A separate switch for each phase consists of a circle of copper studs through the center of which passes a spindle of insulating material. This bears an arm with a spring-loaded segmental contact which bridges a pair of adjacent studs in each of the respective tap positions. Built in tier formation, the three switches are separated by insulating tubes and have a common operating spindle coupled to a hand wheel mounted in the cover. This hand wheel can be locked so as to prevent unauthorized interference.

The necessary surface for natural cooling is furnished by rows of elliptical tubes welded in the long sides of the tank, and additional detachable radiators are mounted at the ends of the tank. This arrangement is designed to conform to the minimum space through which the transformers must pass with all radiators in position. The cooling elements are placed with respect to the windings so as to achieve the minimum difference of oil temperature between the top and bottom of the tank and to insure the lowest possible maximum temperature in any part of the winding.

Construction Records Made by Signal Corps in Italian Advance

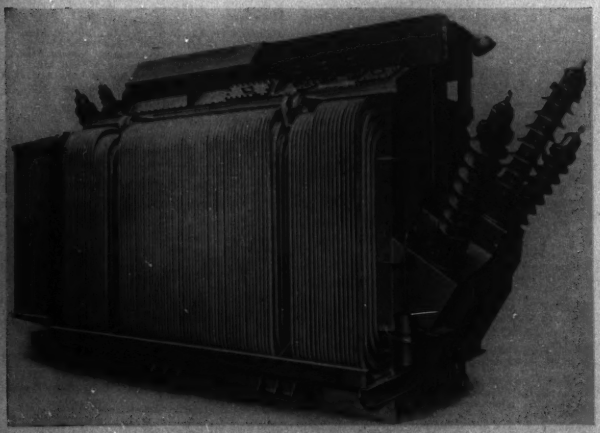
New records for the rapid extension of open-wire circuits were set by the communications men of the Signal Corps during the Fifth Army advance in Italy in May and June.

From the night of May 11, 1944, when the Allied offensive was launched until the end of May the pole line carrying the main Army open-wire axis was stretched to Terracina, a point 60 miles from the breakthrough point by construction elements for six Signal Corps battalions. One construction company was sent to the Anzio beachhead and worked back along the highway to meet the anticipated advance of the teams pushing north from Terracina. In addition to the main axis construction, two open-wire circuits were constructed to provide for the French Corps at Ausonia and two more for a lateral to the British Eighth Army. Work also was commenced on another lateral of two circuits to the Eighth Army.

In June the Signal Corps exceeded even these feats by extending the open-wire circuits a distance of 140 miles. So rapid was the advance of the troops that all available construction personnel of four Signal battalions, augmented by two construction companies, worked at top speed at the task.

Army depots issued, during the month of May, three times the amount of field and assault wire issued during the earlier static period of the war; and in June they issued the impressive totals of 19,500 miles of field wire W110, 5,000 miles of assault wire W130, and 1,500 miles of spiral 4 wire.

Radio circuits and radio teletype service kept pace in performance with the open-wire circuits, but the pigeon service experienced an "encouraging difficulty." May was a big month for the pigeoneers, with 28 combat lofts out on tactical assignments operating from 15 widely distributed front-line locations, and with an average of about 60 messages carried by the birds daily; but in June the front advanced so fast that it was impossible to settle the lofts quickly enough to serve the various Command Posts before a new advance. However, the same speed of advance which prevented the settling of the pigeon lofts prevented the establishment of wire communications to all hospitals, and the pigeons were a satisfactory means of communication for the Medical Corps in sending its daily reports back to Army Headquarters from forward installations.



External view of transportable transformer manufactured by the English Electric Company, Ltd.

Obsolete Walkie-Talkie Sets Salvaged by Signal Corps

When the new SCR 300 model (see *EE, July '44, p. 274*) is distributed for general use among American troops overseas and in the United States, the older SCR 194 and 195 "walkie-talkie" sets are taken apart and salvaged according to instructions from the Signal Corps of the Army Service Forces.

Signal depot men are instructed to disassemble the old models and recover 85 parts, including 27 items which, after inspection and reconditioning, can be used in or with other Signal Corps equipment. Most of the capacitors, resistors, switches, sockets, transformers, handsets, voltmeters, and antennas are re-used either as direct replacements or substitutes for similar components on other types of transmitting–receiving sets. Even the two quartz crystals from the old "walkie-talkie" can be reground for further use by the Signal Corps. Nuts, screws, and washers are sorted and kept for general hardware stock. An example of the meticulous care of the conservation program is the War Department's recommendation that "in removing items such as resistors and capacitors, care should be taken to keep any attached pigtail leads as long as possible. In the event that the pigtail leads are less than one inch in length, the item should be salvaged."

Prisoners of War May Solve Production Lag. Confronted by a Navy schedule of contracts for electrical fuses as much as 18 months behind, the newly organized Vulcanized Fibre Manufacturers Industry Advisory Committee is considering the wider use of German war prisoners in plants to offset the serious labor shortage, according to the War Production Board. The industry also will strive to secure labor priority ratings from the War Manpower Commission to obtain the extra labor needed. A Navy representative informed the committee that there were 43 unfilled contracts among 14 fuse manufacturers, and in addition that the Navy desires to put procurement on a 90-day basis by January 1, 1945.

POSTWAR

ALA Committee Preserves Periodicals for Foreign Libraries

Up to the end of 1943, $160,873.62 had been spent for subscriptions to 325 scholarly and scientific journals to be stored in the United States for postwar distribution to libraries isolated by the war. Such purchases were made possible by an annua grant from the Rockefeller Foundation of from $50,000 to $70,000 since 1941. The fund is administered by the American Library Association's committee on aid to libraries in war areas, originally formed to study ways in which libraries in the United States could help those abroad in their struggle with wartime conditions, and especially to find some means of preserving for later distribution copies of United States publications not shipped in war areas.

Several factors influence orders placed for each periodical: the journal's foreign circulation before the war, the ratio of foreign circulation to total circulation, the number of free or exchange subscriptions, the number of copies available through gifts from subscribers in this country, and the relative importance of the journal to research. In no case have purchases equaled more than half the number of paid institutional subscriptions in Europe and Asia discontinued because of the war, and no funds have been allotted for purchasing periodicals from individuals nor for the acquisition of volumes issued before 1939. However the governments in exile and other groups have made efforts to maintain subscriptions for important libraries in various countries.

The ALA, other library associations, and the constituent societies of the American Council of Learned Societies have prepared lists of outstanding publications in their various fields of interest which were published in the United States from 1939 to 1944. They will be available to private persons and groups interested in the selection of books for foreign libraries.

The committee's purchases have been supplemented by gifts, and in this way back files of important periodicals have been secured to restock libraries that have been damaged or destroyed. No definite decisions on the disposal of books and periodicals can be made until more is known of library conditions in war areas. Present efforts of the committee therefore are confined to collecting material, obtaining all available information about the needs of libraries, and recording what is being done in the same field by other organizations.

Free storage space is difficult to obtain and whenever possible donors are urged to store materials until central storage space is available. Transportation costs are paid, but material accepted for storage is limited to what seems of first importance. Gifts are being stored in a number of libraries in all parts of the country. Prospective donors are asked to report titles and dates of the journals available to the office of the committee Library of Congress Annex, Study 251, Washington, D. C. Shipping instructions then will be forwarded, indicating where and how shipment should be made.

Polish Technical Council for Rehabilitation Formed

A Polish Technical Societies Council composed of Polish and Polish–American engineers to aid in Poland's postwar educational and industrial rehabilitation recently was formed.

As a first step, the group is registering all engineers who would be willing to offer services either to Polish government or industry, or who would be available for service with the American industry in the future export–import activities. In addition the group is co-operating with the Polish refugee engineers in England and Canada in devising plans for postwar rehabilitation aid through provision of consulting service, qualified engineers, and technicians.

J. S. Kozacka, professor of mechanical engineering, Illinois Institute of Technology, Chicago, has been elected president of the council, and Frank Nurczyk, manager of the Polish–American Business Men Association, Chicago, is secretary-treasurer.

OTHER SOCIETIES

$1,000 Award for Young Chemists Honors Doctor Backeland

Establishment of the Leo Hendrick Backeland award by the North Jersey section of the American Chemical Society with the co-operation of the Bakelite Corporation, New York, N. Y., to encourage the creative talents of the younger American chemists, was announced by Horace E. Riley, chairman of the North Jersey section, at the 108th annual meeting of the Society held recently in New York.

The award of $1,000 and a gold medal will be presented biennially to an American chemist who has not yet reached his 40th year in recognition of accomplishments in pure or industrial chemistry. The first award will be made in May 1945. Nominations for the award will be received by the chairman of the North Jersey section, who is also chairman of the award committee, no sooner than October of the calendar year preceding the award and not later than the following December 1. The name of the first recipient and of each one thereafter will be announced at the regular February meeting of the section.

Future Meetings of Other Societies

American Society of Mechanical Engineers. Annual meeting, November 27–December 1, 1944, New York, N. Y.

American Welding Society. Annual meeting, October 16–19, 1944, Cleveland, Ohio.

Electrochemical Society. Fall meeting, October 12–14, 1944, Buffalo, N. Y.

Electronic Parts and Equipment Industry Conference. October 19–21, 1944, Chicago, Ill.

Engineers' Council for Professional Development. Annual meeting, October 20, 1944, New York, N. Y.

Institute of the Aeronautical Sciences. Fall meeting, November 1944, Dayton, Ohio.

National Electrical Manufacturers Association. October 23–27, 1944, New York, N. Y.

National Industrial Chemical Conference and Third National Chemical Exposition. November 15–19, 1944, Chicago, Ill.

Society of Motion Picture Engineers. 56th semiannual fall conference, October 16–18, 1944, New York, N. Y.

By means of the Backeland medal the sponsor and the Society seek to encourage emulation of the career of Leo H. Backeland, best known for his invention of the synthetic resin trade-marked Bakelite. Doctor Backeland was a member of the American Chemical Society for 52 years and served as its president in 1924. A fuller biography will be found in *Electrical Engineering*, April 1944, pages 155–6.

ASA Receives Distinguished Service Award

Presentation of the Army Ordnance Department's Distinguished Service Award to the American Standards Association "in recognition of outstanding and meritorious engineering advisory services in war and peace, for the development, manufacture, and maintenance of Ordnance matériel," recently was made by Brigadier General Stewart E. Reimel, before 80 national trade, technical, and governmental groups that make up ASA's membership. The award has been bestowed upon only one other organization.

In his presentation address, General Reimel declared that recent victories in Europe and Asia never would have been won if the valor and skill of our soldiers had not been matched by the quality of their weapons and if the weapons had not been available in the proper quantities. A vital force in these victories, he said, was the American technique of mass production fostered by principle of interchangeability of parts. He recalled the fact that the early application of this principle by New England gun makers in the 19th century was sponsored by the Ordnance Department. General Reimel praised ASA's share in spreading the doctrine and benefits of mass production to ever-widening fields, as an immeasurable contribution to the industry–Ordnance team in its task of providing our Army with weapons and firepower unsurpassed by those of any other nation.

"That standards of production did exist is in large measure the result of the work that the American Standards Association has done during the past 26 years," he stated.

H. B. Bryans (F '18) accepts the Distinguished Service Award from General Reimel while H. S. Osborne (F '21) and P. G. Agnew (M '19) secretary of the American Standards Association, look on

In reviewing the wartime record of the ASA, General Reimel asserted that since Pearl Harbor the development of more than 100 emergency war Standards has been undertaken by ASA, and some 86 of these have been completed and are now in use.

"For the Army and Navy," he went on, "these war Standards have been developed to solve specific procurement problems; to aid in the design of new equipment; to help protect workmen in their plants; to enable both Services to use identical specifications and thus simplify inspection problems; and to help make spare parts interchangeable in the field."

As an indication of the immensity of the Army's standardization problem, General Reimel mentioned the fact that the procurement list of the Ordnance Department alone includes 2,200 separate major items for which nearly 400,000 different kinds of spare parts are needed for repair work.

"The Association's war work also has aided industry," he added, "in broadening its sources of supply, in subcontracting, in production control, in training employees, in preventing accidents and industrial diseases; in fact, in the whole production process.

"The War Production Board has enlisted the aid of the Association in developing standards to form the basis of limitation and conservation orders. The Office of Price Administration has used its Standards in price regulations and in rationing," he concluded.

In accepting the award, H. B. Bryans (F '18) executive vice-president of the Philadelphia (Pa.) Electric Company and president of the ASA pointed out that much of the war work of the ASA has been made possible because the Association occupies a position as a federation of trade and technical associations and government departments and because of its unique position in the field of standards of a regulatory nature.

In commenting on the technical work that won the award, H. S. Osborne (F '21) chief engineer of the American Telephone and Telegraph Company, New York, N. Y., past president of AIEE, and president of the Standards council, stated that three fourths of the ASA's work during the past year has been on jobs of direct value to the war effort. Besides the 86 war Standards, 134 of the 266 American War Standards completed since Pearl Harbor are of interest to Army Ordnance, he said.

ASA Moves Its Headquarters. With its prewar staff nearly doubled by the greatly increased work on Standards arising out of the war, the American Standards Association has found it necessary to expand its office space beyond the facilities of the Engineering Societies Building, 29 West 39th Street, New York, N. Y. Therefore the ASA has transferred its headquarters to the Grand Central Terminal Office Building, 70 East 45th Street, New York 17, N. Y.

India Technical Association Organized in the United States

Formation of the India Technical Association to promote closer association among Indians interested in the industrial development of India and among American engineers and manufacturers with a similar interest and to guide Indian students in gaining practical experience in the United States, recently was announced by N. R. Joshi (A '43) acting secretary of the new association which has its headquarters in New York, N. Y.

The Association hopes to make knowledge about the present industrial needs of India more widespread among American engineers and manufacturers, according to Mr. Joshi. It contemplates preparation of a list of American industrial organizations wishing to co-operate with and assist if necessary the Indian industrialists in setting up projects. A list of manufacturing firms desiring to offer practical training facilities to Indian students and thus to establish better relations between India and America also will be compiled.

In reviewing the features of India's present industrial status which would make it attractive to American enterprise, Mr. Joshi pointed out that India's transportation and communication facilities have been developed to a stage suitable for raising her industrial position in the world. Among the possibilities for investment he mentioned India's resources of coal, iron, mica, copper, manganese, and her potential hydroelectric power resources, second only to the United States. The growing national interest in transforming India's industrial outlook, evidenced by the Bombay Plan originated by leading Indian industrialists, also would support such projects, he said.

Edison Electric Institute Expands Its Board

The Edison Electric Institute recently adopted an amended form of its constitution which provides for a board of directors and an advisory committee to replace the former board of trustees and operating committee and thus effects a broader representation of the industry.

Responsibility for government and administration is centered in the board of directors with a minimum of 15 and a maximum of 45 members, one third of whom will retire from office each year. The board will be elected from among the officers and employees of member companies for a term of three years. The appointed advisory committee will consist of no more than 30 members chosen from the senior executive officers of member companies and will have the duty of exchanging information and counsel on matters affecting the whole electric utility industry.

1943 Insulation Research Reviewed By NRC Chemistry Committee

"Contributions of the Chemist to Insulation Research," a 65-page pamphlet which embraces the period from January 1943 to January 1944, has been issued by the committee on chemistry of the conference on electrical insulation of the National Research Council in the belief that the increased demand for this annual publication means that it fills an important wartime need.

The six articles in the current issue cover: progress in the field of anomalous dispersion, rubber electrical insulation, insulating paper, synthetic plastic electrical-insulation oils, and ceramic electrical insulation. A comprehensive bibliography is appended to each article. Copies may be obtained without charge, as long as the supply lasts, from G. T. Kohman, Bell Telephone Laboratories, Murray Hill, N. J., who is chairman of the committee on chemistry.

Ultrahigh-Frequency Text Published. The recently published "Ultrahigh-Frequency Radio Engineering," by W. L. Emery (A '37) now connected with the United States Naval Research Laboratory, Washing-

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Pentode Ignitrons for Electronic Power Converters

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Synopsis: The name "pentode ignitron" has been applied to a high-voltage tube used for rectification and inversion in electronic converters. It is a sealed steel tube having an anode, three grids, and a mercury-pool cathode. The tube is of the gas-filled type with control characteristics similar to those of the thyratron. An ignitor establishes a cathode spot each cycle on the mercury pool. The cathode spot is stabilized at low anode currents by the use of an auxiliary holding anode. The functions of the three grids are somewhat similar to those in the pentode vacuum tube, but the manner of use is quite different. The first grid, or one nearest the anode, is used as an intermediate anode to divide potential gradients across the tube during nonconducting periods. The second, or center grid, is used to control the starting of the conduction period and the third, or outer grid, as a shield to permit rapid deionization of the space between the control and shield grids.

The introduction of multiple grids in ignitron tubes provides certain characteristics which are essential to inverter operation. It is the purpose of this paper to describe some of these characteristics, and the design and construction of the pentode ignitron tube.

These tubes are the ones installed in the power converter described in the companion papers.[1,2-5]

THE history and development of suitable electronic tubes and circuits for high-voltage power-conversion systems is discussed in a companion paper.[1] Briefly, the first power unit after laboratory tests consisted of a 40–60-cycle 5,000-kw power converter. The tubes for this unit were of the thyratron* type. The nonsynchronous link operated at a direct potential of 30,000 volts and a current of approximately 170 amperes. Power from the 40-cycle system was converted to direct current through 12 phanotron tubes connected in a cascade arrangement of two three-phase double-way rectifier circuits. The direct current was converted to 60-cycle a-c power through 12 thyratrons connected in a similar arrangement of double-way inverter circuits. Initial operation was remarkably free from any basic trouble. Operation over a period of some five years demonstrated the complete practicability of sealed electronic tubes for this type of service.

The development of the ignitor[3] opened the possibility of utilizing the control features of the thyratron design in a tube having the inherent high-current capacity of the mercury pool. Operating experience with sealed steel ignitrons[3] which were developed for service in the 250- to 600-volt power-conversion fields indicated the basic soundness of the ignitron principle of starting a new cathode spot each conducting cycle. These ignitrons are of sufficient current capacity to give power rectifiers of 75 to 1,000 kw, depending on voltage. Similar ignitrons operate in welding service with precise cycle-by-cycle control of currents from 1,000 to 10,000 amperes. The rectifier ignitrons were designed to have the lowest possible arc loss consistent with essentially complete freedom from arc-backs under normal operation conditions. The designs consist of an anode, a mercury-pool cathode, ignitors, and a small auxiliary anode for maintaining the cathode spot during the normal conducting period in case the main anode current falls below the value (about three amperes) at which the arc is stable. There is a minimum of shielding. Voltage control is obtained by shifting the phase angle at which the ignitor is fired. Variation in the starting or ignition time is small (of the order of 50 to 100 microseconds) with the usual excitation circuits.[4] Deionization time at the end of conduction is relatively long because of the open construction. Deionization time in an ignitron is the time required for the ionization in the space to decay sufficiently so that cathode spots are not reestablished if the anode is made positive. In a thyratron, it is the time required for ion sheaths to close the holes in the grids and effectively isolate the anode from the main body of the tube. Ignitron tubes have operated successfully as inverters,[5] but the required commutation time is in general too long to permit optimum operation. For such service, the grid-control characteristics of the thyratron tube for accurate starting and rapid deionization, in combination with the high current capacity of the mercury pool, seemed to offer attractive possibilities for the design of higher-voltage higher-current tubes.

Description

The pentode ignitron tube consists of an anode, a mercury pool cathode with ignitors and auxiliary anodes, and three grids. The similarity of the construction—an anode, three grids, and a cathode—to that of the pentode vacuum tube, suggested the use of pentode ignitron as a name. The general design is shown in Figures 1 and 2. The anode is surrounded by the grids. Starting from the anode, the first grid acts as an intermediate anode to divide potential gradients during nonconducting periods. The next or control grid determines the time of starting and reduces the deionization period at the end of conduction. The outer or shield grid acts in a dual capacity to pick up the arc at the beginning of conduction and to shield the rest of the grid–anode structure from residual ionization after conduction. The cathode has three ignitors, only one of which need be used at a time. There are also two auxiliary holding anodes. One auxiliary anode maintains cathode-spot excitation for low anode currents and the other is used for control purposes as described later.

The tube conversion capacity is of the

Table I

Maximum peak inverse or forward voltage, volts	20,000
Maximum anode current, amperes:	
Instantaneous	900
Average:	
Continuous	150
Two hours	200
One minute	300
Minimum water flow, gallons per minute	2
Minimum inlet water temperature, C	35
Maximum inlet water temperature, C	45

Paper 44-147, recommended by the AIEE committees on electronics and industrial power applications for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944. Manuscript submitted April 27, 1944; made available for printing May 18, 1944.

H. C. STEINER, J. L. ZEHNER, and H. E. ZUVERS are in the electronics department, General Electric Company, Schenectady, N. Y.

* Thyratron is a generic term describing a gas-discharge thermionic-cathode tube in which one or more grids control the starting of the current electrostatically.

Figure 1. The pentode ignitron tube used in the 20,000-kw electronic power converter

order of 1,500 kw per tube. Companion papers[6-8] describe the installation and application of the pentode ignitrons in a 20,000-kw 25-to-60-cycle electronic power converter. The converter is divided into two 10,000-kw units. Each unit consists of two sections, a rectifier and an inverter, whose functions may be reversed, depending on the desired direction of power flow. There are 12 tubes in each section connected in two three-phase double-way rectifiers in cascade. The nonsynchronous d-c tie operates at approximately 30,000 volts and 340 amperes.

Development

The design of the tube is based on work by K. H. Kingdon and E. J. Lawton[9] on the cause of arc-back and on the possibility of increasing the operating voltage of gas-filled tubes through potential division.

A single-anode tube has a fairly definite maximum voltage limit at which arc-back occurs. This limit depends on load conditions, vapor pressure, and tube design. Reduction of potential gradients by means of potential dividing anodes would seem to offer the possibility of increasing the operating voltage. The principle has been successfully applied in high-vacuum rectifier tubes for X-ray service. In the case of gas-filled tubes, and particularly for tubes operating at relatively high currents, it is impracticable to divide the inverse potential at the end of commutation since the ion densities are too great. A few degrees later in phase angle, however, ionization has decreased to values which permit successful use of potential division.

Arc-back or inverse current conduction has been an interesting subject of discussion for many investigators.[10-12] The occurrence is definitely of a random nature, and the time may vary[13] from immediately after conduction when ion densities are greatest to any point in the inverse cycle. One obvious cause is too high vapor pressure due to lack of sufficient cooling or to mercury droplets striking hot objects and transiently increasing the vapor pressure above the voltage breakdown of the gas. The relation between vapor pressure and temperature for equilibrium conditions is shown in Figure 3. Mercury droplets are ejected from the surface of the pool by the action of the cathode spots. These droplets leave the pool with a random velocity so that the space above the pool and around the anode is filled with flying droplets during both the conducting and inverse parts of the cycle. These droplets do not always cause arc-back even when striking a hot anode, but it seems probable that a sufficient concentration of them may well do so.

As a result of tests on the influence of contaminating materials such as glass, quartz, asbestos, and so forth, on the rate of arc-back, the hypothesis has been proposed by Doctor Kingdon that arc-backs are due basically to the collection of charges on small insulating patches on the anode. If the potential gradient exceeds the field emission requirements of the base material, arc-back results. Whether or not a sufficient potential gradient is established depends on the rate at which ions strike the insulating particle and the rate at which the charge leaks off. The rate at which ions strike the anode is proportional to the ion density in the space in front of the anode at the end of conduction, and the negative voltage to which the anode is driven. The density of ionization bears a direct relationship to the current, and at the end of conduction both the current and inverse voltage may be defined in terms of circuit parameters. Test results indicate that the rate of arc-back is proportional to the product of the initial inverse voltage and the rate of current change. For each design of tube, therefore, a rate can be determined in terms of an arc-back factor δ which will

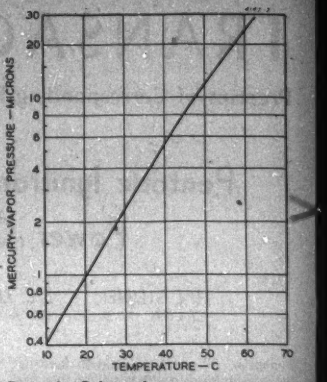


Figure 3. Relation between mercury-vapor pressure and temperature for equilibrium conditions

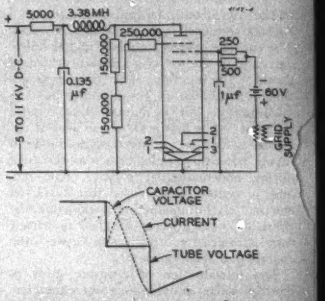


Figure 4. Single-tube inverter test circuit for investigating effect of circuit on arc-back rate

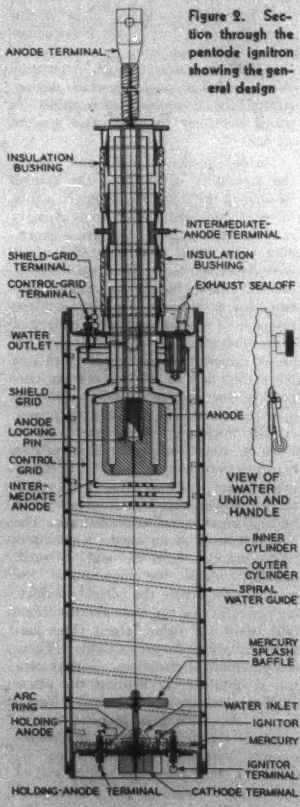


Figure 2. Section through the pentode ignitron showing the general design

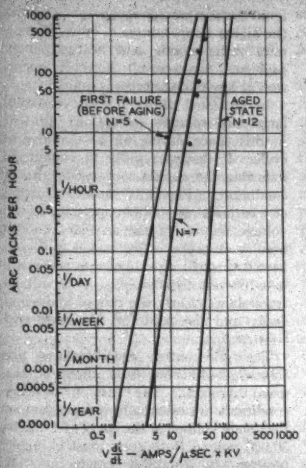


Figure 5. Relation between circuit arc-back factor $V(di/dt)$ and rate of arc-back for the conditions shown in Figure 4

permit its performance under other circuit conditions to be predicted. That is:

$$\delta = V\frac{di}{dt}$$

where

V = negative anode potential at end of commutation in kilovolts

$\frac{di}{dt}$ = rate of current change at the end of commutation in amperes per microsecond

Developmental tests under varying circuit conditions of current and voltage were made to determine the arc-back rate. The tests were made in a single-tube inverter circuit as shown in Figure 4. The duty was made sufficiently high to cause rapid failure (one to ten times per minute), and the data obtained are shown in Figure 5. The solid lines are a plot of the Poisson probability formula:

$$P(n) = \frac{e^{-\mu}\mu^n}{n!}$$

where

$P(n)$ = probability of arc-back (arc-backs per number of trials in unit time)

μ = average number of ions striking an area ΔA in time Δt. This is proportional to $V\frac{di}{dt}$

n = number of ions striking ΔA in Δt time for failure

With the proper choice of μ and n the curve may be made to fit the test data, and the probable values of arc-back rates for more normal circuit constants determined from its extrapolation.

Arc-back tests were also made under actual power conditions in a biphase single-way rectifier–inverter circuit shown in Figure 6. The transformer capacity was of the order of 1,000 kw and the arc-back factor 1.5–2 for no phase retard. At 25,000 volts peak inverse, 150 amperes current, a limit of 60 degrees centigrade (24½ microns) outlet water temperature was found. At 12,500 volts, 300 amperes, the temperature was 71 degrees centigrade (50 microns). These extremely high limits tend to reflect the gas-breakdown point for a particular pressure and spacing.

Considerable experience and data are being accumulated to substantiate the validity of the insulating-patch theory

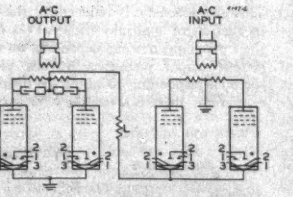


Figure 6. A 1,000-kw operation-test circuit for rectification and inversion

and the definition of circuit duty in terms of an arc-back factor. Correlation between test conditions and actual performance in power circuits is sufficiently close to indicate the importance of the concept in understanding the mechanism of arc-back.

Control measurements were taken with a rotary switch in the circuit shown in Figure 7. In this case, a quarter-wave of current is passed through the tube under test. At the peak of the wave, the current is rapidly commutated to a second tube. Shortly after this, the mechanical switch opens and at a given interval later, a positive voltage is applied to the anode of the tube under test. Its ability to withstand this voltage is a measure of its deionization time, that is, its ability to regain control. Figure 8 shows the test results. The effect of gas pressure and grid-circuit impedance is clearly indicated.

Construction

The pentode ignitron is arranged for water cooling, that is, the mercury-vapor pressure is controlled by circulating water of the proper temperature through a water jacket surrounding the tube walls. A spiral water guide imparts a velocity of approximately five feet per second to the water to insure efficient heat transfer. An adequate amount of mercury-condensing surface is provided in the tube to maintain a low vapor pressure during overloads and at the same time allow for a reasonable variation of cooling-water temperature. Sudden increases in vapor pressure due to flying mercury droplets hitting hot anode and grid surfaces are prevented by the addition of a graphite splash baffle. The effects of ionization and vapor pressure are further controlled by suitable shielding in the anode stem and by the action of the grids.

Electrode connections are brought out through permanently vacuum-tight insulation bushings consisting of high-resistance borosilicate glass sealed to fernico.

All water-cooled surfaces of this tube are made of stainless steel which is highly resistant to corrosion. The inner cylinder is formed out of sheet material and a

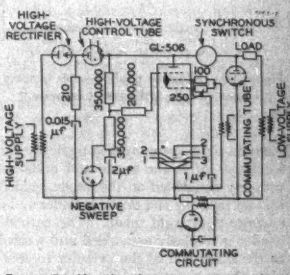
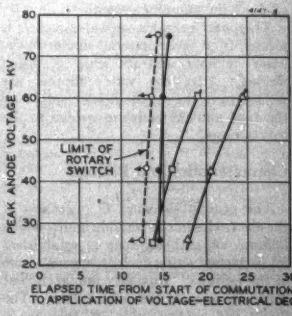


Figure 7. Kingdon–Lawton rotary-switch circuit for determining the recovery of grid control following commutation


PEAK ANODE VOLTAGE — KV
LIMIT OF ROTARY SWITCH
ELAPSED TIME FROM START OF COMMUTATION TO APPLICATION OF VOLTAGE—ELECTRICAL DEG

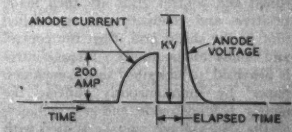


Figure 8. Grid-control recovery characteristics following commutation

- ▲ 60 C_j control-grid resistance 500 ohms
- □ 60 C_j control-grid resistance 100 ohms
- ○ 40 C_j control-grid resistance 100 or 250 ohms
- ● 40 C_j control-grid resistance 500 ohms

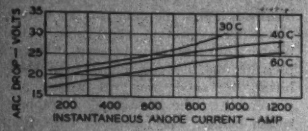


Figure 9. Arc-drop characteristics for cooling-water temperature of 30–60 degrees centigrade

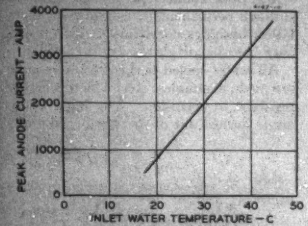


Figure 10. Effect of cooling-water temperatures on tube fault-current capacity

vacuum-tight seam weld is made by arc welding. After the anode and grids are properly assembled on the anode header, it is set into one end of the cylinder and a vacuum-tight weld made. The cathode header is similarly assembled and welded to the other end of the cylinder to complete the vacuum envelope of the tube.

At this point the tube receives a very rigorous degassing treatment during which the mercury is introduced and at the end of which it is permanently sealed off from the pumping system.

The outer cylinder, or water jacket, is formed from sheet material similar to the inner cylinder and its seam is fusion welded. After the water nipples are welded to it, the outer cylinder is slid over the tube and the ends are welded to the spacer rings.

Characteristics and Ratings

The general sequence of operation of the electrodes in the pentode ignitron is as follows. A cathode spot is established for each conducting cycle by means of one of the ignitors. Auxiliary anode current starts as soon as the ignitor fires. The shield and control grids are then made positive, and conduction is established first to the shield grid, then the control and finally to the anode. Phase control is obtained, as described in a companion paper[7] by simultaneously shifting the ignitor, holding anode, and grid voltages; or the grid voltage may be shifted with respect to the ignitor.

The introduction of multiple grids in the tube design considerably influences the tube characteristics. The arc drop is higher than that which is obtained in the lower voltage ignitrons. Figure 9 shows this characteristic. Some of the increase in arc drop is due to the length of arc path below the grids themselves. The arc drop plotted is the average value over the conducting period, that is, the arc-drop wave shape of gas-filled tubes is, in general, higher at the beginning of the period when there is a deficiency of ions and vapor and lower at the end of the conducting period. These values may vary from the mean by one to two volts. For the data in Figure 9, the tubes were operated in a three-phase single-way circuit with resistance load. The arc drop was measured by means of a cathode-ray oscilloscope and amplifier with an inverse-voltage blocking circuit. The abscissa is the maximum or peak of the current carried.

The amount of fault current which the tube can conduct is shown in Figure 10. This characteristic is reduced by the introduction of multiple grids. Two distinct phenomena occur depending on the mercury-vapor pressure. At low pressures corresponding to about 20 degrees centigrade, there is a tendency for surges

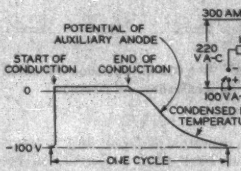


Figure 11. Potential of a probe near the cathode used to indicate ion density after conduction

if the current exceeds to any appreciable extent the value indicated. This phenomena is due to so-called "starvation" of the arc. In effect, all of the gas molecules in the grid openings are ionized and swept out of the immediate region before new molecules can diffuse in from the gas outside. The current tends to cease abruptly for an instant and this rate of current change, in connection with circuit inductances associated with the current path, generates high voltages. It is common practice in mercury-arc equipment to protect associated transformers with suitable resistance-capacitance filters or Thyrite.

At higher vapor pressures, corresponding to temperatures of 40 degrees centigrade and above, and higher currents, the arc drop tends to reach a value where cathode spots may form spontaneously on the walls of the tube. If this happens too frequently, sufficient metal may be vaporized into the mercury pool to cause wetting of the ignitors. Higher vapor pressures reduce the arc drop and increase the fault-current capacity, and it is desirable to operate the tube at as high a vapor pressure as is consistent with freedom from arc-back or loss of control. The pentode ignitron tube was designed to operate at the higher temperatures in order to minimize water-cooling and heat-exchanger problems. As a result, however, operation at low temperatures is limited.

In gas-filled tubes having relatively large open volumes, ionization is present in this space during all of the inverse cycle. It decays rapidly in magnitude following the cessation of anode-current conduction. Figure 11 shows a drawing of a cathode-ray oscilloscope trace of the voltage on one of the auxiliary anodes used as a probe. The anode was connected through a one-megohm resistance to a 100-volt negative bias. The voltage trace shows clearly the rate of ionization decay and the need for the shield-grid construction.

The grid-control characteristics are somewhat different from those of the usual thyratron. The "turn on" or firing conditions are essentially independent of the anode voltage in the range of 1,000 to 30,000 volts. Both grids must be made positive to establish conduction. If either is negative, the tube will not conduct. Conduction must first be established to the shield grid and then to the control grid. The optimum point for this occurs at the peak of the ignition-current impulse when an ionization density equivalent to the 40- to 50-ampere ignitor current is reached. Beyond this point, the ionization corresponds to that of the auxiliary-anode current and slightly higher shield-grid voltages are required. Under ordinary conditions, the shield-grid potential to establish conduction is of the order of 15 to 30 volts. Control-grid conduction voltages are correspondingly low. Figure 12 shows the grid-circuit control system used in the operation test, Figure 6.

The essential ratings defining the tube characteristics are tabulated in Table I.

Application

The application of electronic tubes involves careful co-ordination of the tube characteristics with the circuit requirements. The application engineer is concerned primarily with the over-all performance of the apparatus. The tube engineer must be concerned with the requirements as the tube sees them. While it is necessary to consider the average and rms voltages and currents, it is mandatory to consider the instantaneous.

Figures 13 and 14 show the anode-current and anode-to-cathode-voltage wave shapes for a tube in a three-phase double-way rectifier and in an inverter. The voltage traces are the logical result of rectifier and inverter operation in a three-phase system. In the case of the rectifier, the anode voltage is driven sharply negative at the instant the current transfer is complete. The resultant arc-back factor $V(di/dt)$ and the stress on the tube will be high when the voltage is high. It is in-

creased with greater angles of retard since both the initial inverse voltage and the rate of current change increase. The remaining notches in the inverse voltage are the result of commutations between other tubes. In the case of the inverter, the small negative-voltage region represents the time for deionization and regaining grid control, as well as margin for possible phase-angle changes between the anode and grid circuits. Loss of commutation in an inverter tube results in a d-c short circuit on the rectifier 60 degrees later when the second tube on the same phase starts to conduct. Sudden voltage changes as represented by the vertical parts of the curve transiently may effect other elements in the circuit or tube. Arc-backs during the commutation period, interestingly enough, do not always result in loss of control. Currents are

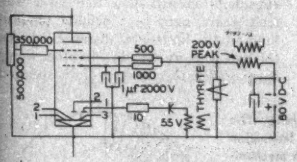


Figure 12. Grid circuit used in the operation set, Figure 6

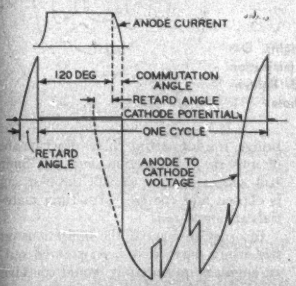


Figure 13. Diagram showing the instantaneous anode current and anode-to-cathode voltage for a tube in a three-phase double-way rectifier circuit

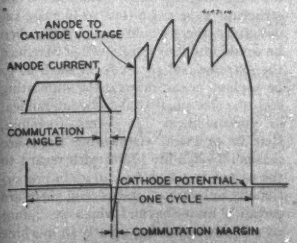


Figure 14. Anode current and anode-to-cathode voltage for operation in a three-phase double-way inverter circuit

small and commutate out at the voltage reversal, and the arc does not restrike unless the ionization is high.

Ample power in the ignition circuits is essential to insure complete reliability of firing for possible voltage fluctuations or changes in the ignitor. A single-cycle misfire in a rectifier results only in a partial loss of output and a corresponding increase in duty on the tube which must carry current for a longer period. A single-cycle misfire in an inverter, however, results in a short circuit on the rectifier since the direct current may then flow through the two tubes on one phase rather than traverse the transformer windings. In such a case, recovery is obtained by blocking the rectifier through ignitor and grid control to stop the direct current, and then gradually reapplying voltage. The entire cycle requires less than one-third second to restore power.[1,7]

Under certain conditions of residual ionization and high voltage, cathode spots may be formed in event of an ignitor misfire. The process is erratic, but the mechanism is interesting. If the grids are made positive, electrons are drawn from the space below the grid. These electrons attain considerable energy if there is no replenishing source to maintain the plasma electron and ion balance. In striking the grids they release secondary electrons. Ionization follows and the gradients established are sufficient to form cathode spots on projecting points in the cathode section or on the walls of the tube. The process is entirely prevented if the grids are held negative. Therefore, to prevent the possible uncontrolled formation of cathode spots the grid circuit is energized through one of the auxiliary anodes, as described in a companion paper.[7] The possibility of occurrence is remote, but its control illustrates the exactness which can be obtained when there is complete co-ordination between the tube and circuit characteristics.

Ignition, in general, with the excitation circuits employed, is both accurate and reliable.

The successful application of an electronic tube depends on its performance and life. In performance, it must equal or exceed that of other devices supplying the same function or it must provide some unique function in order to merit consideration. Life then becomes largely a matter of economics. In most power-conversion applications it is a balance between the savings due to the increased efficiency of the electronic apparatus and the cost of tube renewals. Industrial-tube life is excellent and in general results in a satisfactory operating cost. Since there is no way of running accelerated life tests, a conclusive statement cannot be made in the case of the pentode ignitron, but in view of experience with similar tubes and the basic design features involved, it is expected that an average life of at least five years will be obtained.

Conclusion

The development and application of the pentode ignitron marks a new and advanced step in the program of developing electronic tubes for power-conversion purposes. The performance to date and the characteristics of the 20,000-kw electronic power converter are described in associated papers. Quite obviously, additional units could be added to give higher voltages, and the d-c link itself could be extended to form a complete transmission system. As experience is gained, the tubes themselves will undoubtedly undergo design refinements and improvements.

The development and application of any electronic tube is interesting—that of the pentode ignitron extremely so. Its design and manufacture required the collaboration and the skill of many individuals, and their co-operation and assistance is gratefully acknowledged. In any extended development of this nature, vision and faith are required on the part of management and the authors wish to acknowledge specifically the encouragement and assistance of E. F. W. Alexanderson, R. C. Muir, and the late C. W. Stone.

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Dimensional Studies of Lightweight Motors for Aircraft

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Synopsis: The study of what happens to the proportions of a machine as the size of the machine is changed not only is interesting to imaginative engineers but also is very useful in teaching the engineer how best to design a particular machine. By understanding the relationship which exists between size and any desired useful characteristic, it is possible to make better use of experience which has been obtained on machines of different output in determining the probably best proportions of a new device. It is the purpose of the present paper to point out how relatively complicated machines may be compared by a method similar to dimensional analysis for the purpose of establishing such relationships as output per pound or output per cubic inch. Obviously, the conclusions which will be reached by such a study will be different as different original assumptions are established and it is therefore important to determine carefully what limitations on machine performance are really fundamental. Once such assumptions have been established soundly, it seems possible to arrive at very useful dimensional-analysis conclusions in connection with relatively complicated machines.

The Effect of Size on Design Proportions

IT is not recorded by Jonathan Swift in describing the visit of Lemuel Gulliver to the island of Lilliput whether Gulliver observed the difference in engineering proportions which must of necessity have taken place between the machines of people of our size and those of the diminutive people who inhabited that island. If he had reported such differences they would have been the inspiration for some very interesting engineering philosophy concerning changing proportions as the dimensions of devices are changed in a way similar to that of microphotographing V-mail letters. A brief consideration of what happens when size is changed will show that, for equal performance, the best proportions of a machine are seldom the same. This idea is visualized easily if consideration be given to a simple mechanical structure and the conditions surrounding the change of its proportions as one of its dimensions is changed.

One of the simplest mechanical structures is that of a bar of structural steel suspended from one end and acted upon by the force of gravity. In considering the characteristics of such a piece of mechanism as the length of the bar is increased, the conclusion shortly is reached that it would be impossible to increase the length of the bar indefinitely if it be presumed that the cross section of the bar remain constant. When the structural steel bar had reached a length of approximately 33,000 feet, or six miles, a further increase in the length of the bar would cause it to break at the point of support under its own weight and it would, of course, be incapable of sustaining any external load. If, instead of being made of structural steel, the bar had been made of the rarer tungsten, the per unit strength of the material would, of course, be increased approximately four times, but unfortunately the weight of the metal also would be increased approximately two and one-half times and the length of the rod which would be self-supporting would be increased only 60 per cent and the limit in length, while greater, would be just as definite as for the steel rod.

We are forced to conclude, therefore, that in the case of this particular structure one of the dimensions, the length of the bar, could not be increased indefinitely although the sectional dimensions of the bar could. It follows, therefore, that, if we had a miniature steel bar four inches long and 0.0001 inch in diameter suspended from one end and we wished to increase all dimensions of the bar proportionally, we could do so until each dimension was multiplied by 100,000 after which the bar would break of its own weight. Furthermore, as all the dimensions of the bar were increased, the useful load which could be attached to the extreme end would decrease from an initial value of 100,000 times its own weight to zero when each dimension was increased by 100,000 times.

An interesting sidelight of the above comparison is that it has been found that drawn wires of small cross section have a greater per unit strength than do drawn bars of larger section. For this reason, if the cross section of the rod or wire which we have been considering were made exceedingly small, for example 0.005 inch in diameter, the strength of the steel itself might be doubled or even trebled without any change in the chemical composition of the material. We see therefore that, instead of dealing with a constant for the ultimate per unit strength of a material, we actually have to deal with a variable which is dependent on size.

A slightly more complicated structure is that of a uniform flexible rod suspended from both ends in such way that the rod takes on the shape of a catenary. A brief consideration will show that for a catenary there must be a definite physical limit in the horizontal distance between the two supported ends. In other words there is a limit to the span of a suspension bridge, the supporting cables of which are of uniform cross section, and this limit still will exist even though the best sag is chosen and the best structural materials are employed.

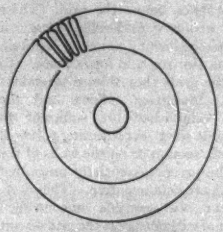

Figure 1 (left). D-c rotor lamination with teeth mechanically weak

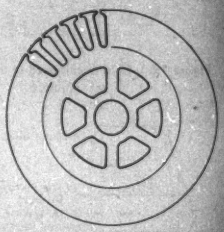

Figure 2 (right). D-c rotor lamination made with lightening holes

In order to combat the limitations on size which have just been pointed out, an engineer immediately would conceive the possibility of employing tapered sections and by such an engineering trick he would be able greatly to extend the dimensional limits to which his structure could be produced without failing under its own weight. But if the size of his structure were permitted to increase indefinitely, there would come a time when he would find it necessary either to reduce the extreme end to a size so small as to be useless, or to increase the supporting end to a size so great as to be impractical or uneconomical. It seems, therefore, that in practical engineering there are reasonably definite limits with regard to the extent to which we can go in proportionally enlarging a device and there are certainly limits beyond which we cannot go without sacrificing greatly in machine efficiency.

Engineers, because they see so many things to do and so many things to be

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improved, are inclined to be busy people. Because of their tendency to be busy they seldom take enough time to philosophize on their problems and thus to recognize and obtain the best possible use of their experience. Ordinarily they are concerned more with producing one particular design to meet the requirements of the problem in hand, and once satisfactory performance has been attained, they tend to lose further interest and proceed with the next problem. Where time is not too important and competition not too severe, the tendency of cumulative experience is to produce finally a product of substantially the best proportions. However, when there is immediate pressure for an ultimate design of considerably altered size, the usual specific approach is likely to be either ineffective or expensive.

Analysis of Proportions of Lightweight Motors for Aircraft Use

The recent requirement brought about by the pressure of war necessity for many different d-c motors of minimum weight per horsepower for operating various devices on war planes is one in which the dimensional-analysis point of view can be brought to bear profitably. In determining the best proportions for such motors it is necessary to consider the best operating speed, the best number of poles, and the best relation between diameter and length in order that maximum output per pound may be secured. Because of the current interest in this problem insofar as war aircraft are concerned, it is one of the purposes of this paper to present a method for comparing d-c motors of different sizes. Another object of the paper is to describe a few of the conclusions which have been reached as a result of the study of such motors.

Basis for D-C Aircraft-Motor Study

It seems in consideration of the design of d-c motors for aircraft that the most important problems are specifically the following:

1. What are the best proportions for a d-c motor when weight is a prime consideration?
2. What are the relative horsepower per pound values which can be obtained from two, four, six, eight, and more poles?
3. How does the horsepower per pound vary with the stacking length?
4. How does the horsepower per pound vary with the size of the motor?

The structure of a d-c motor is so complicated as to make it entirely impractical to undertake to develop a function which would express the output of such a motor in terms of several independent variables, and it is necessary to apply practical considerations such as are used in design work in order to reduce the problem to one which can be treated analytically. Such considerations will be explained briefly.

It is obvious that the more complicated the structure of a motor (the more slots we put in the rotor, for example) the less efficient will be the use of the space and material which we allot to its construction. If too many slots are put in the rotor (Figure 1), the teeth may become flimsy, and it may be necessary to increase their widths for purely mechanical reasons. In addition, since the walls of each slot must be insulated in preparation for the winding, with a larger number of slots the amount of space which must be taken for slot insulation will be greater than for a small number of slots. For this reason it is desirable to maintain the number of rotor slots at a minimum in order to be able to crowd into a small space the maximum amount of active material. In direct conflict with the desire for a small number of rotor slots is the desire for good commutation, and in order to obtain good commutation a relatively large number of rotor slots must be used. It is necessary to use experience and designer's judgment to determine the number of rotor slots per pole which constitutes the best compromise.

The type of mechanical construction which is chosen for both the rotor and the stator will affect the utilization of material and the over-all size of the motor. Consideration must be given to whether unused iron under the rotor slots will be punched out (Figure 2) in order to lighten the rotor, or whether a riveted type, a shell type, or some other form of stator construction will be used. Once these constructional details have been fixed upon, it is possible to proceed with the analysis by making additional simplifying assumptions.

In order to avoid unnecessary complication it is well to confine attention to the electric part of the motor and to allow the end bells, the ventilation, and the bearings to intrude only insofar as they affect the electric construction. Even the commutator and brush mechanism may be relegated to the sidelines with the assumption that for any given horsepower of output the brushes must be of a certain cross section area and the commutator must be of sufficient size to receive such brushes. On the basis of this point of view there will be little difference in commutator size and weight for a given machine output with changes in electric proportions even with changes in numbers of poles.

If the motor is of the shunt type or is compounded only slightly, it can be assumed that the flux densities in the motor will be reasonably constant except for armature reaction and that the iron is worked very close to the saturation point. Under these conditions the performance of the motor is very similar to that of a separately excited machine, and the variation in output characteristics may be assumed to come almost entirely from the variation in rotor proportions.

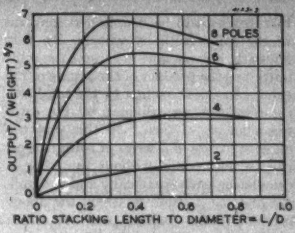

Figure 3. Calculated curves, output characteristics versus poles and L/D

If we are dealing with a constant field flux, the output of a d-c motor is a function of the amount of conductivity in the rotor winding and is independent of the actual number of turns on the winding provided the impressed voltage is assumed to be adjustable to obtain best motor performance. In other words, it is unnecessary for us to concern ourselves with the actual details of the rotor winding itself provided we know the resistance of the winding corresponding to a given number of rotor-winding turns. This point of view allows us to take the mean length of the rotor turn divided by the total area of the rotor conductors as a measure of the output of the rotor.

If by design modification it becomes possible to increase the field flux of a d-c motor, the effect is to cause the motor to run more slowly unless there is a proportional increase in the voltage impressed upon the rotor. Since the speed is usually a part of the specifications, it would be normal either to modify the rotor winding or to increase the impressed voltage by such an amount as to maintain the speed of the motor at the same value as before the increase in the field flux. If the voltage per turn of the rotor be modified to maintain constant speed, the actual rotor resistance per impressed volt will vary inversely as the square of the field flux, and, consequently, the output of the rotor also will vary as the square of the field flux.

From the above considerations the complete expression for the output of a constant-flux d-c motor operating at constant speed is

$$\text{Output} = (\text{field flux})^2 \times (\text{rotor conductivity}) \quad (1)$$

From the above expression it is possible to start with a rotor diameter and stacking length chosen to give approximately the output desired and to lay out within that diameter a series of rotor punching designs differing from one another by the width of the rotor teeth and other changes which follow consistently therefrom. On the assumption that the

flux density will be maintained constant in the rotor teeth by varying the field strength, it is possible to express the rotor output as the product of the square of the total rotor-tooth section by the total useful rotor-slot area divided by the rotor mean length of turn. In this way the relative merits of a series of rotor designs can be determined without the labor of calculating each specifically and in detail. By plotting a curve in which the above product is the ordinate and the width of the rotor tooth the abscissa, it is possible to select the particular rotor design which will give the maximum possible output within the assumed dimensions. With a change in the assumed stacking length it would be expected that the rotor punching design would change somewhat in order to secure the best proportions, although actual trials, fortunately, show that the effect of stacking length on the best punching design is not very pronounced. Once the best proportions for a rotor having a given ratio of diameter to stacking length have been determined it can be shown that a proportional change in all dimensions of the rotor will not affect the condition of maxima. In other words, if a certain rotor design having an outside diameter of D is found to be the best design for a given stacking length, L, then a rotor having every dimension reduced to one half the size of the first mentioned rotor will be found to have the best proportions for a rotor of that diameter and length. With this in mind it is possible to apply dimensional analysis to the rotor design and thus compare rotors having different sizes but which are otherwise similar.

The dimensional equation corresponding to the field flux of a rotor with saturated teeth is

$$\text{Field flux} = L^2 \tag{2}$$

The dimensional equation corresponding to the conductivity of a rotor winding as already defined is

$$\text{Conductivity} = L^3/L = L \tag{3}$$

By substituting the dimensional values for flux and conductivity in equation 1, the dimensional equation for output is

$$\text{Output} = (L^2)^2 \times L = L^5 \tag{4}$$

The dimensional equation for weight is:

$$\text{Weight} = L^3 \tag{5}$$

$$L = (\text{weight})^{1/3} \tag{6}$$

When equation 6 is substituted for L in equation 4, we learn the output in terms of the weight, which is

$$\text{Output} = (\text{weight})^{5/3} \tag{7}$$

Equation 7 shows that the output of a motor under the conditions assumed is not linear with the weight as often is assumed, but instead varies as the $^5/_3$ power of the weight. In other words the larger a motor becomes, the greater will be its output per pound. In order to compare two different designs it is necessary to reduce them to two designs of equal weight. This may be done by dividing the output of a design by the $^5/_3$ power of its weight, which is equivalent to reducing the design to a proportional one having a weight of one pound. On this basis, the dimensionless number which measures the output per pound of any design under the conditions assumed is

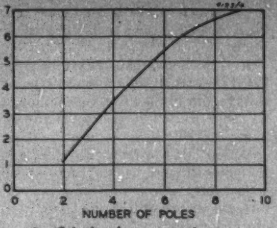

Figure 4. Calculated curve, maximum output characteristic versus number of poles

$$\text{Design effectiveness} = \text{output}/(\text{weight})^{5/3} \tag{8}$$

By making a series of designs, as previously suggested, to determine the best design for a given diameter and length of rotor and then repeating the operation for other ratios of L/D, it is possible to plot design effectiveness figures and to learn what ratio of L/D gives the maximum output per pound for a motor of any given number of poles. A similar investigation for other numbers of poles permits plotting a curve showing the maximum output per pound as a function of the number of poles of the motor.

It is not the purpose of the present paper to go into the laborious side of the problem, but only to indicate in a general way the method to be followed in making an analysis of this sort and to show the types of curves which are obtained in such an investigation. These curves are given in Figures 3 and 4.

Effect of Speed on Output

In many cases because of the use of a gear train, the speed at which an aircraft motor operates will be left to the judgment of the designer of the motor and the gear train. Under such conditions it is desirable to be able to compare the over-all weight of a high-speed motor driving a long gear train with a low-speed motor equipped with a shorter train. The foregoing discussion furnishes the means for making such a comparison.

The speed of a constant-flux d-c motor can be increased by increasing the volts per turn which are impressed on the rotor winding. If the volts per turn are increased in ratio a, the increase may be accomplished by reducing the number of rotor turns in ratio $1/a$. Since a reduction in turns produces a corresponding reduction in length of conductor and, in addition, a corresponding permissible increase in the area of the conductor, the actual resistance of the rotor will be reduced in ratio $1/a^2$. If the duty cycle is so short that heating is not a limit in the motor performance, the change in speed will be accompanied by an increase in output which is proportional to the square of the change in the volts per turn. In other words, where heating is not a limit

$$\text{Output} = \text{speed}^2 \tag{9}$$

Of course, it will be noticed that an increase in the speed of a motor should change the ratio of the weight of the commutator and brushes to the weight of the active material of the motor and therefore should modify by that amount any conclusions which are reached in connection with the active material of the motor.

If the temperature of the rotor be a limit, it is necessary to maintain the same current density in the rotor regardless of the speed. In such case, the output of the motor would be directly proportional to the speed, and for a given motor size and constant rotor current density, we might write

$$\text{Output} = \text{speed} \tag{10}$$

It depends upon whether the duty cycle of the motor is short or long which of the foregoing two relationships will be assumed to exist and, if temperature is not a limit, a more complete expression to be used in comparing the output of two motors than that given in equation 8 might be written as follows:

$$\text{Design effectiveness} = [\text{output} \div (\text{weight})^{5/3}](\text{speed})^2 \tag{11}$$

Conclusions

It is especially interesting to notice that under the assumed conditions there is a considerable advantage in output per pound in increasing the number of poles of a motor until eight or ten poles have been reached. Beyond this point there is relatively less improvement to be gained by increasing the poles, and manufacturing considerations and considerations of a practical nature dictate that no more poles than are necessary to accomplish the desired result should be used.

In considering the value of the curves which have been obtained by the admittedly high-handed method of analysis which has been proposed herein, there may arise questions concerning the validity of the conclusions in connection with motors other than the constant-field shunt type of motor which has been discussed. It probably might be better to start with different and perhaps more complicated original assumptions in the

Design and Operating Characteristics of Modern Dry-Type Air-Cooled Transformers

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A DRY-TYPE transformer may be defined as a transformer devoid of all liquids and one whose core and coils and associated parts are cooled by the natural or forced circulation of air.

Dry-type air-cooled transformers are not new; in fact, the first transformer ever built was of dry-type design. However, until a relatively recent date, dry-type transformers have been usually of small kilovolt-ampere rating and low voltage, or of relatively large size of the air-blast type. These transformers have been constructed with organic insulating substances, known as class *A* insulation. Class *A* insulation is not fireproof.

In 1936, a new kind of dry-type transformer was developed. These transformers are now built in ratings as large as 4,000 kva and they are cooled simply by the natural circulation of air through their core and coil structures. With forced-air cooling the capacity of these transformers may be increased materially.

These dry-type transformers are explosion-proof and essentially fireproof because their major insulation is principally air and porcelain. In fact, their insulation structures are made up largely of inorganic substances, such as porcelain, glass, asbestos, and mica, or combinations of these and other substances, bonded together with a heat-resisting varnish. Combinations of these substances are now defined in American Standard *C*-57.1 as class *B* insulation.

Temperature Limitations

Briefly stated, the present definition of class *B* insulation covers inorganic substances such as mica, asbestos, and fiber glass in built-up form with organic binding substances. A small portion of class *A* materials may be used for structural purposes provided the electrical and mechanical properties of the insulating structure are not impaired by a continuous temperature of 130 degrees centigrade.

Although the continuous temperature limit specified for class *B* insulation was established some time ago at 130 degrees centigrade it is obvious from the definition of class *B* insulation that there might be different combinations of organic and inorganic substances that would have temperature limits varying over a considerable temperature range. This is further indicated in AIEE Standards number 1 by the statement: "Materially higher 'hottest-spot' temperatures may be satisfactory for particular forms of class *B* insulation, . . ." Consequently, it has been recognized that certain combinations of these substances will withstand higher operating temperatures than 130 degrees centigrade. Such a combination of insulating materials has been used in developing the dry-type transformer described in this paper.

Now, let us consider just how these insulating materials are used in the construction of these transformers so that they will give satisfactory service over long periods of time even though under sustained rated load their "hottest-spot" copper temperatures may be in excess of 130 degrees centigrade.

Figure 1 is a photograph showing the structural detail of the type of winding commonly used in these transformers for operating voltages up to 5,000. Figure 2 shows the type of winding used for voltages above 5,000 and up to and including 15,000.

Winding conductors are insulated with glass or asbestos. Sections of the high- and low-voltage windings are separated by porcelain, mica, or asbestos. High-voltage windings are supported on porcelain. Porcelain is used to center the high- and low-voltage winding assembly on the core. Porcelain spacers form large

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The author acknowledges the valuable assistance relative to the measurement of temperatures received from Paul Narbut of the small power and network transformer division of the Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Table I. Insulating-Barrier Hottest-Spot Temperature Rise Expressed as Per Cent of the Hottest-Spot Copper Temperature Rise

Duct Length, Inches	Duct Width		
	1/2 Inch	3/4 Inch	1 1/2 Inches
15	58	52	52
30	67	58	52
45	73	62	52

consideration of the series motor and perhaps even in the consideration of a shunt type of motor in which the armature reaction very seriously affects the field distribution. However it is true that for motors of the aircraft type it probably will be found that under the normal operating conditions the strength of the series field is so great as substantially to saturate the magnetic structure of the motor and to produce conditions more nearly like those proposed in this discussion than might appear at first glance. It is probably also true that there is enough similarity between a series motor and a shunt motor to make the end result of an individual study of each reach approximately the same conclusion.

The procedure outlined in the paper has not included the study of the field structure of the machine, although, actually, work which already has been carried out did include the field structure in order to complete the story and obtain an accurate picture of the output per pound of active material in the motor.

It is believed that the conclusions which have been reached in connection with the study should make it possible to compare motors of this type which differ greatly from one another in size more accurately than by the more conventional D^2L method of comparing designs.

General Comments

As mentioned originally in connection with the comments on proportions of mechanical structures, there are factors which dictate that as the size of an electrical machine is increased indefinitely its proportions must change. For this reason, a study of machine effectiveness made over a considerable range in size must be accompanied by a review at intervals of the design limitations to make certain that a factor which was important in a small machine does not become negligible in a large machine or vice versa.

One important factor which was omitted purposely from the present study was the effect of iron loss. Such loss will be seen to vary in respect to the output as the output is increased while the flux density is maintained constant; because with flux density constant the iron loss will vary as the first power of the weight, whereas the output has been shown to vary as the $^3/_4$ power of the weight. With two similar machines differing in size the iron loss of the large machine should be less important in comparison with the output.

air-ducts between sections of the high-voltage winding and between the low-voltage winding and the core. A clear cylindrical duct of air separates the low-voltage winding from the high-voltage winding. Dirt which falls into this high-potential area simply drops through to the bottom of the transformer case. Horizontal creepage surfaces in high-potential areas are eliminated. High-voltage and low-voltage leads are supported on or terminated in porcelain insulators.

Figure 3 shows a cross section of a low-voltage and high-voltage winding and the insulation structure. The windings are individually treated with a heat-resisting thermoset varnish and baked at a high temperature. The core and winding assemblies are also treated with the same heat-resisting varnish and baked at a high temperature which eliminates the residual volatile matter. This treatment imparts a smooth, tough, glossy finish to the complete structure which makes it highly resistant to heat, dirt, and moisture.

Glass, an inorganic substance, is highly resistant to temperature. It is also essentially nonhygroscopic. However, in order to insulate copper suitably with glass for use as a winding conductor, it is necessary to bond the glass fibers and filaments mechanically to the copper. This bond imparts the mechanical stability required to use the insulated conductor in winding coils and assembling them into transformers. Tests made on windings treated with this bond show that it will withstand continuous temperatures of the order of 160 degrees centigrade for long periods of time with but little loss of its mechanical cementing properties. The insulation is not materially affected by an amount of moisture that may be expected under operating conditions. Operating experience has confirmed that it is not necessary for the varnish to retain its original properties fully during the operating life of the transformers, as will be shown later.

Figure 1. Structural detail of a barrel-type low-voltage winding

Figure 2. Structural detail of a disk-type high-voltage winding

Temperature Distribution

Let us now consider what the operating temperatures of the windings and the insulation structures may be and how the transformers are assembled to withstand these temperatures.

According to American Standard *C-57.1*, dry-type transformers constructed with class *B* insulation (combinations of organic and inorganic substances) are permitted to operate at a continuous average copper temperature rise of 80 degrees centigrade, measured by the resistance method. With the present maximum permissible temperature of 130 degrees centigrade for class *B* insulation and with an ambient temperature of 40 degrees centigrade the hottest-spot copper allowance in a transformer would be only 10 degrees centigrade. This seems inconsistent because even in properly designed dry-type transformers of small kilovolt-ampere rating, aside from those of large kilovolt-ampere rating, relatively high temperature gradients may exist and it is not practicable to limit the hottest-spot allowance to 10 degrees centigrade.

If we consider the actual temperatures to which the insulation of a dry-type transformer may be subjected, it is necessary to recognize the existence of temperature gradients within the transformer itself. The insulation nearest the winding copper is necessarily subjected to higher temperatures than the insulation physically removed from the copper. Thus the turn insulation, directly in thermal contact with the copper, is, for all practical purposes, subjected to the same temperatures as the copper. On the other hand, insulating barriers which are not in thermal contact with the copper will be at appreciably lower temperatures than the windings.

To obtain data on temperature gradients within dry-type transformers, tests have been made on model winding assemblies, representative of small as well as large transformers, and on actual transformers, to determine (a) copper temperatures and their distribution in the windings of transformers as representative of the insulation in direct contact with the copper, and (b) temperatures of the insulating barriers in transformers as related to the copper temperatures and the space between the copper and the barriers.

Figure 4 shows a model winding assembly on which a series of tests were made by passing a certain current through the winding until steady temperature conditions were obtained and recorded by thermocouple readings. Thermocouples were

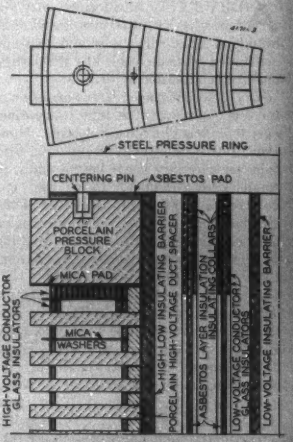

Figure 3. Cross section of the low-voltage and high-voltage winding and the insulation structure

used because they afford the most suitable experimental means of measuring local temperatures.

The winding assembly consisted of three sections, each section 15 inches long. The three sections could be used either separately or stacked one upon the other, thus giving three effective winding lengths. The width of the cooling duct separating the winding from the insulating barrier was made variable by using barriers of different diameters. Thermocouple junctions were soldered to the copper conductors. A three-quarter-inch retaining collar at the ends of each section reduced the effective length of the winding assembly to 13½ inches per section.

In all these tests, it was found that the hottest-spot copper temperature is located at a distance of 10 to 15 per cent below the top of the winding, the higher value applying to the wider ducts. For any specific duct width and length, the hottest-spot copper temperature rise was found to be proportional to the average copper temperature rise, thus giving a constant value for the ratio of the

hottest-spot copper temperature rise to the average copper temperature rise. This ratio was found to vary with the width and length of the air duct separating the winding from the insulating barrier. This is shown in Figure 5. The highest value was 1.36 for the longest and narrowest duct.

Due to the presence of a radial gradient and a reduced radiation at the ends of the winding because of the retaining collars, the ratio of the hottest-spot copper temperature rise to the average copper temperature rise may be expected to be greater in the windings of actual transformers when compared with that obtained in the model winding.

To determine the location of the hottest-spot temperature in the windings of actual transformers, a series of tests was made on a 300-kva 2,400-volt single-phase transformer, and on several 500- to 800-kva 13,800-volt three-phase transformers. All of these transformers had a pancake or disk-type outer high-voltage winding with three-eighths-inch air ducts separating the disk sections. A three-eighths-inch air duct separated the inside of the winding from the outside of its insulating barrier. The inner or low-voltage windings were of the cylindrical or barrel type of two- and four-layer construction having air ducts from five-eighths inch to seven-eighths inch wide, separating the layers from each other, and from the inner and outer insulating barriers.

The 300-kva transformer had a number of thermocouples placed in the low-voltage and high-voltage windings, the object being, primarily, to locate the hottest spot. Tests made on this transformer show that for the same average temperature in each winding, the upper portion of the inner or low-voltage winding is considerably hotter than the hottest part of the outer or high-voltage winding, thus definitely locating the hottest-spot of the assembly in the upper part of the inner winding. A study of the radial temperature distribution in the inner winding shows the existence of a temperature gradient from layer to layer with the highest temperature in the outer layer.

The highest value of the ratio of the hottest-spot copper temperature rise to the average copper temperature rise recorded for natural draft operation on the 500- and 800-kva transformers, was 1.41. With forced-air operation of these transformers and with the same average copper temperature rise, the value of this ratio, in general, may tend to be somewhat higher. In particular, this may be due to the more turbulent action of the air which exists with high air velocities. In an extreme case, however, a high value of the ratio of the hottest-spot copper temperature rise to the average copper temperature rise may be traced to an unequal distribution of the air flow between the phases of the transformer and a consequent inequality of the average copper temperature in the different phases.

A comparison of actual copper and barrier temperatures obtained is as follows: Based on an average temperature rise of the windings of 80 degrees centigrade as determined by the resistance method, the hottest-spot copper temperature rise will range from approximately 100 to 115 degrees centigrade. With

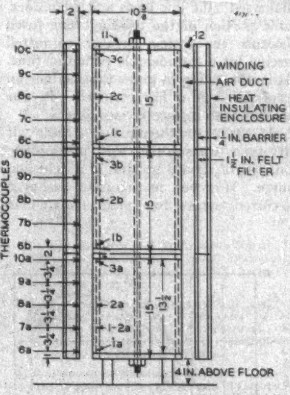

Figure 4. Model winding and barrier assembly used for temperature distribution tests

an ambient temperature of 40 degrees centigrade the hottest-spot temperature of the copper will range from approximately 140 to 155 degrees centigrade.

Data obtained on the model winding assembly, Figure 4, show temperatures on the surface of the insulating barrier adjacent to the winding but separated from it by air ducts of variable widths. Figure 6 shows a typical temperature distribution in the winding and the barrier with a one-half-inch-wide air duct separating the winding and the barrier. Expressed as a fraction of the hottest-spot copper temperature rise, the value of the barrier hottest-spot temperature rise varies from 0.58 to 0.73.

It has been shown that the barrier insulation in these transformers will operate at appreciably lower temperatures than those of the windings. See Table I and Figure 6. From these data, it may be noted that the hottest-spot temperature of the barrier insulation in properly designed dry-type transformers having an 80-degree centigrade average winding temperature rise as measured by the resistance method will be approximately 115 degrees centigrade; that is, it will range from 25 to 40 degrees centigrade below the hottest-spot winding temperature. Life tests on the barrier insulation used in these transformers show that it will withstand a continuous temperature of 130 degrees centigrade without detrimentally affecting its electrical and mechanical strength.

It is important to note that none of the insulation which may reach a temperature in excess of 130 degrees centigrade is subjected to line-to-line or line-to-ground voltage stresses. The voltage where temperatures above 130 degrees centigrade may occur is limited to winding turn-to-turn stresses which do not exceed 80 volts.

Service Tests

A 500-kva 13,800-volt three-phase dry-type transformer was moved outdoors and given a rain test for 16 days with a water spray having a precipitation of 0.2 inch per minute applied continuously around the case. The case had screened openings in the bottom and the top. The transformer carried no load but was excited at 13,800 volts for 16 out of each 24 hours. During the period without excitation, the rain test was continued.

After this extreme test, lasting for 16 days, the transformer was subjected to the standard dielectric test of 31,000 volts from the high-voltage winding to the low-voltage winding and to ground for 60 seconds with no signs of distress whatever. While these dry-type transformers are intended only for indoor application where very little moisture is likely to be present, these results are reassuring when condensation or the effects of high humidity during installation and operation are considered.

A 150-kva 2,400-volt three-phase dry-type transformer, enclosed by an open-screened case, has been under test for more than 20 months, supplying power for the operation of motors and other equipment. The load cycle begins each week at 8:00 a.m. on Monday. The test is conducted in a relative humidity of approximately 95 per cent and at a room temperature varying from 32 to 50 degrees centigrade. At 4:00 p.m. each day, through Monday to Saturday, the load is removed but the transformer is kept energized and left to "soak" overnight. From 4:00 p.m. on Saturday until 8:00 a.m. on Monday, the transformer remains energized and the 95 per cent relative humidity is maintained. Under these extreme conditions this transformer has given continuous service and there are no indications of a deterioration of the varnish or of the insulation. The test is being continued.

Another dry-type transformer, enclosed by a sheet-steel case with louvers, having a normal rating of 480 volts, has been subjected to temperature and moisture tests for more than 2,000 hours, operating under the following cycle. The load was adjusted so that the average maximum continuous winding tempera-

ture, determined by thermocouples, is 175 degrees centigrade. The load is maintained for 16 of each 24 hours during five days of each week. At the end of each 16-hour load period, a water spray is directed against the transformer case for five minutes. Following this, the transformer is allowed to stand eight hours of each day without power applied. At the end of each weekly cycle, immediately following the last 16-hour load period, the standard dielectric test of 4,000 volts is made from the high-voltage winding to the low-voltage winding and to ground. Following this test, the water spray is applied for five minutes. The transformer then remains de-energized for 56 hours when power is again

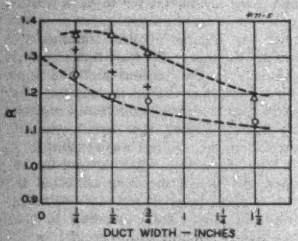

Figure 5. Variation of ratio of temperature rises

$$R = \frac{\text{hottest-spot temperature rise}}{\text{average temperature rise}}$$

O—Duct length 15 inches
+—Duct length 30 inches
Δ—Duct length 45 inches

applied and the weekly test cycle is repeated.

A careful examination of the transformer after the 2,000-hour test period disclosed some deterioration of the varnish but no insulation failures have occurred nor were there any indications of a decrease in the dielectric strength of the insulation. The test is being continued.

Operating Experience

Many transformers of this type have been in continuous operation for more than seven years. Today, there are nearly 2,000 transformers in service totaling approximately 1,000,000 kva. Never has a breakdown of the winding insulation occurred in any of these transformers which could be directly attributed to an excessive hot-spot winding temperature, an accumulation of dirt, the effects of condensation, or operation in a humid atmosphere.

With nearly 2,000 transformers in operation, four transformers have failed in service. It is of interest to note the cause of these failures, the resulting damage to the windings of the transformers, and what was necessary to put the transformers back into service.

A 600-kva three-phase 6,900-volt dry-type transformer flashed over as the result of a severe lightning surge. The voltage impressed on the high-voltage winding was estimated to be in excess of 100 kv. Connected directly to the secondary of a large bank of power transformers, this dry-type transformer had no lightning protection of any kind. The high-voltage winding was severely damaged; the line leads and a considerable portion of the winding were fused because the system breaker permitted arcing for a considerable period of time. It is interesting to know that neither an explosion nor a fire occurred. It was necessary to replace the windings.

A 1,000-kva three-phase 13,800-volt dry-type transformer was temporarily put out of service because of a lightning surge. However, in this case, flashover occurred across two plain rectangular

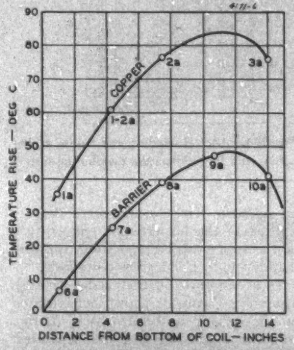

Figure 6. Typical curve of the temperature distribution in one section of a model winding assembly, showing the relation between the winding and the barrier temperatures for a one-half-inch duct width

porcelain insulators which were used to support the high-voltage leads. As a secondary result, a small arc occurred at one point between the two outer turns of the top high-voltage coil section of one phase. The turn insulation was only slightly damaged. Permanent repair of the winding was made and the transformer was put back into service within two hours after the failure. Later, the rectangular-shaped porcelain insulators were replaced with round corrugated insulators.

Two other dry-type transformers failed after short periods of service. One failure was caused by a short-circuit between two adjacent turns in the high-voltage winding, apparently the result of a poor joint which punctured the insulation. Repair was effected easily and quickly. The other transformer outage was caused by the flashover of a porcelain lead support which may have been due to an excessive accumulation of conducting dirt. The only repair necessary was to replace the lead support.

There have been instances where a number of these dry-type transformers operated at overloads ranging from 150 to 200 per cent of rated load for continuous periods of time in excess of 24 hours. The windings must have been subjected to temperatures appreciably in excess of 160 degrees centigrade.

For instance, a bank of 150-kva 4,000-volt transformers carried in excess of 150 per cent of rated load for a period of nearly three days. This overload occurred nearly four years ago. A careful inspection of these transformers did not indicate any noticeable deterioration of the insulation. These transformers have continued to give uninterrupted service.

Two years ago, another bank of dry-type transformers carried approximately double load for more than 24 hours. These transformers have continued to operate without any ill effects of this heavy overload.

A 600-kva 13,800-volt three-phase dry-type transformer, after having been in service over one year, was operated at 200 per cent of rated load for a period of 30 hours. It is estimated that the maximum temperature of the windings was in excess of 225 degrees centigrade. No failure occurred and the transformer is continuing in service.

Conclusions

Because the major insulation of these dry-type transformers is primarily air, it is unaffected by temperatures within the operating range.

There are available special winding-conductor insulations which come within the scope of the present definition of class *B* insulation. These conductor insulations will withstand satisfactorily hottest-spot temperatures in excess of 130 degrees centigrade. Other parts of the insulation structure are subject to temperatures which are well within the established limits for the materials used.

Experience with dry-type transformers of this type operating under extremely humid conditions show that the effects of moisture are not a limiting factor.

Tests on these transformers, together with an operating record of more than seven years, give ample proof that these modern dry-type air-cooled transformers operating under normal as well as the usual abnormal conditions of service, may be expected to give continuous reliable service.

Bibliography of Relay Literature 1940–1943

AIEE RELAY SUBCOMMITTEE
Working Group on Relay Bibliography

THIS interim report was prepared by the working group on bibliography of the relay subcommittee of the AIEE committee on protective devices, in order to make immediately available this material to the entire industry. Previously it has been available only to the relay subcommittee in annual reports and then published at ten-year intervals. However, it was felt that the urgency of the relay problems brought about by the war emergency makes it desirable to have this information more generally available.

A "Bibliography of Relay Literature, 1927–1939" was published in pamphlet form in July 1941 and in the AIEE TRANSACTIONS, Volume 60, 1941, pages 1435–47.

The articles listed in this bibliography (1940 to 1943) include all those appearing in the AIEE TRANSACTIONS or ELECTRICAL ENGINEERING as well as in most of the chief technical publications of the world from January 1940 through December 1943. These articles are subdivided into several sections. In each section the entries are numbered consecutively and listed alphabetically by years, the first significant word of the title determining the alphabetical position.

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Formulas for Calculating Short-Circuit Forces Between Channels Located Back to Back

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IN 1937 Arnold[1] published an analytic procedure enabling the designer of a single-phase two-conductor bus to determine combinations of conductor spacing and cross section that render the proximity effect zero—hence combinations that render the a-c resistance, and thus the eddy-current loss, a *minimum*. For explicit details the reader is referred to Arnold's paper. For our purpose it suffices to remark that in general the designer is afforded an indefinite number of combinations (of conductor spacing and cross section) from which to choose; that the exact cross sections determined by the theory are not simple in shape; that as the ratio of conductor spacing to perimeter of conductor cross section increases, the equivalent structural shape associated with a particular conductor spacing shifts from rectangular strap to channel to circular or square tubular conductor, that the a-c resistance, and hence the eddy-current loss, can be calculated from a given simple formula; and that the accuracy of this formula and the correctness of the general theory are verified by experimental data set forth in the paper.

Despite, however, the availability and the obvious usefulness of this general theory, it would seem that no considerable use, if any, has yet been made of it. In some part, no doubt, this neglect is due to lack of knowledge of it: Arnold's paper was published in the *Journal* of the Institution of Electrical Engineers, a British periodical which in this country enjoys but little circulation outside of engineering libraries or the technical departments of a few of the larger public libraries. In other part, however, this neglect doubtlessly can be attributed to the fact that, largely, a-c industrial-bus design is polyphase and has as its desideratum the achievement of minimum inductance, hence minimum reactance voltage drop. Designs achieving this end involve closely spaced conductors, thus greater than minimum eddy-current losses, whereas practical designs achieving minimum eddy-current losses involve fairly widely spaced conductors, thus increased reactance voltage drop.

In those instances, however, where single-phase busses are to be designed and minimum reactance is not so much the desideratum as is minimum eddy-current loss, Arnold's theory affords preferred designs. In consequence, it is of interest to the designer of such busses that there be available to him formulas enabling calculation of the electrical and mechanical performance of designs stemming from Arnold's theory. This, as already mentioned, yields conductor cross sections to be approximated by standard structural shapes: rectangular strap, channel, and circular or square tubular conductors.

Now formulas essential for calculating the a-c resistance, a-c inductance, mutual electromagnetic forces on short circuit, and other conductor parameters essential to knowledge of the electrical and mechanical (short-circuit) performance of the bus are available for rectangular strap and circular or square tubular conductors.[2] As regards (uniformly thick) channel conductors located back to back, Arnold has advanced a formula for calculating the a-c resistance and Higgins[3] has advanced a formula for calculating the mutual electromagnetic forces exerted between the conductors on short circuit. *But no formulas for the inductance have been published hitherto.* Yet, inasmuch as among the various combinations of conductor spacing and cross section afforded by Arnold's theory, that combination which affords the best all-around design is usually one comprised of moderately spaced channels placed back to back, it is most desirable to have formulas for the inductance. Such formulas have been derived by Schwantz and Higgins in a master-of-science thesis done by W. Schwantz under the supervision of T. J. Higgins, "Formulas for the Inductance of Busses Comprised of Channels Located Back to Back."

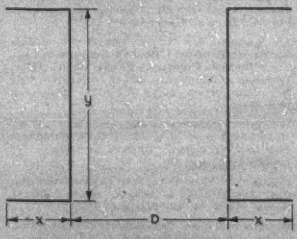

Figure 1

Subsequent to the derivation of and through the use of these formulas, the present writer has been able to derive new and improved formulas for calculating the mutual electromagnetic forces exerted on short circuit. These formulas—easier to use, more rapid in convergence, capable in general of greater accuracy than the earlier formula previously mentioned—are presented in this paper. Use of them considerably simplifies calculation of bus-bar support stresses.

The mechanical forces acting on bus-bar supports during short circuit are determined both by the magnitudes of the mutual electromagnetic forces exerted among the bus conductors and by the elastic properties of the supporting structure: its motional resistance, natural frequencies, and physical nature and arrangement. Comprehensive mathematical studies, substantiated by experimental data, of the individual and collective efforts of these factors and general methods for calculating the magnitudes involved have been advanced by Schurig and Sayre,[4] Dahlgren,[5,6] Eigermann,[7] Pilcher,[8] and Aebi.[9] In shorter articles based on the work of the first-named Schurig, Fricke and Sayre[10]—Tanberg,[11] Specht,[12] Edson,[13] and others[14] have presented certain charts, nomograms, and short cuts that facilitate the numerical labor incident to actual calculation. In consequence of the work of these men, it may be taken that if the designer has knowledge of the physical make-up of the bus structure and of the mutual electromagnetic forces exerted among the bus conductors, he can readily calculate the forces on the bus supports. Obviously, knowledge of the bus structure is immediately available to the designer. Accordingly, if there are also available to him formulas for calculating the mutual electromagnetic forces, he has all that is essential to calculation of the bus support stresses.

Such formulas are derived in this paper, it being assumed that the conductors are nonmagnetic and of such length that end effects are negligible and carry currents distributed uniformly over the cross sections, and that these cross sections are so thin they may be considered to be comprised of line segments (Figure 1).

Of these four assumptions the first and second are commonly satisfied in practice. Re the third, though skin and proximity effects are always present on a-c busses (however, the latter can be largely annulled by use of Arnold's analysis) at power frequencies and normal conductor spacings, their effect on the magnitudes of the electromagnetic forces is, as Beetz[15] has discussed at length, vanishingly small; whence this assumption introduces error negligible with reference to the accuracy

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required in calculating short-circuit forces and enables solution of an otherwise intractable problem. Finally, the assumption of negligible thickness affords formulas that yield values substantially identical with those calculated from the previously mentioned earlier-derived formula for uniformly thick conductors and yet require but a tithe of the numerical computation—whence the labor involved, the time required, and the possibilities of numerical error are considerably reduced.

The desired formulas obtained—by simple differentiation of the known formula for the inductance of the bus with cross section as in Figure 1—their use is illustrated by the numerical solution of a typical problem in bus design.

Derivation of the General Formulas

As derived by Schwantz and Higgins, the inductance per unit length of a circuit comprised of two identical channels located back to back as in Figure 1 is

$$L=-(y+2x)^{-2}[2[y^3-(D+2x)^3]\log[y^2+(D+2x)^2]-4[y^3-(D+x)^3]+2y(D+x)]\times\log[y^2+(D+x)^2]+8yD\log(y^2+D^2)-4[(y^3-x^3)-2xy]\log(y^2+x^2)-4(D+2x)^2\times\log(D+2x)+8(D+x)^2\log(D+x)+12y^2\log y-8D^2\log D+8x^2\log x+8y(D+2x)\tan^{-1}(y/D+2x)-8[2y\times(D+x)+(D+x)^3-y^3]\tan^{-1}(y/D+x)-8(y^2-D^2)\tan^{-1}(y/D)-8(y^2+2xy-x^2)\times\tan^{-1}(y/x)+4\pi y(y+2x)] \quad (1)$$

From fundamental electromagnetic theory, the energy W in the magnetic field associated with a unit length of the circuit when it carries current I is

$$W=LI^2/2 \quad (2)$$

and the mutual electromagnetic force F exerted between the conductors is

$$F=\partial W/\partial D \quad (3)$$

Substituting equation 1 in equation 2, substituting the resulting expression in equation 3, performing the indicated differentiation, and collecting terms yields

$$F=-4I^2(y+2x)^{-2}[-\tfrac{1}{2}(D+2x)\log[y^2+(D+2x)^2]+(D+x)\log[y^2+(D+x)^2]-y\times\log[y^2+(D+x)^2]+y\log(y^2+D^2)-(D+2x)\log(D+2x)+2(D+x)\log(D+x)-2D\log D+y\tan^{-1}(y/D+2x)-2(y+D+x)\tan^{-1}(y/D+x)+2D\times\tan^{-1}(y/D)] \quad (4)$$

Simplicity and increased accuracy of numerical computation stem from combining the logarithmic terms according to the rules for addition and subtraction of logarithms. In such manner we obtain from equation 4

$$F=-4I^2(y+2x)^{-2}[(D/2)\times\log[y^2+(D+2x)^2](D+2x)^2D^{-4}+(D+x)\times\log[y^2+(D+x)^2](D+x)^2[y^2+(D+2x)^2]^{-1}(D+2x)^{-2}-y\log[y^2+(D+x)^2](y^2+D^2)^{-1}+y\tan^{-1}(y/D+2x)-2(y+D+x)\tan^{-1}(y/D+x)+2D\times\tan^{-1}(y/D)] \quad (5)$$

Finally, if we take $a=D/y$, $b=(D+x)/y$, and $c=(D+2x)/y$, equation 5 can be written

$$F=2kI^2/D \quad (6)$$

wherein k is a dimensionless parameter to be calculated either from

$$k=[-2Dy/(y+2x)^2][(a/2)\times\log[c^2(1+c^2)/a^4]+b\log[b^2(1+b^2)\div c^2(1+c^2)]-\log[(1+b^2)/(1+a^2)]+\tan^{-1}(1/c)-2(b+1)\tan^{-1}(1/b)+2a\times\tan^{-1}(1/a)] \quad (7)$$

or

$$k=[-2Dy/(y+2x)^2][(a/2)\times\log[c^2(1+c^2)/a^4]+b\log[b^2(1+b^2)/c^2\times(1+c^2)]-\log[(1+b^2)/(1+a^2)]-\tan^{-1}c+2(b+1)\tan^{-1}b-2a\times\tan^{-1}a+\pi(a-b-0.5)] \quad (8)$$

equation 8 being obtained from equation 7 by use of the trigonometric identity, $\tan^{-1}X+\tan^{-1}(1/X)=\pi/2$.

Alternatively, if we take $A=y/D$, $B=(D+x)/D$, and $C=(D+2x)/D$, equation 5 can again be written in the form of equation 6, but therein k is now given by

$$k=[-2D^2/(y+2x)^2][\tfrac{1}{2}\log(A^2+C^2)\times C^2+B\log[B^2(A^2+B^2)/C^2(A^2+C^2)]-A\times\log[(A^2+B^2)/(A^2+1)]+A\tan^{-1}(A/C)-2(A+B)\tan^{-1}(A/B)+2\tan^{-1}A] \quad (9)$$

or

$$k=[-2D^2/(y+2x)^2][\tfrac{1}{2}\log(A^2+C^2)\times C^2+B\log[B^2(A^2+B^2)/C^2(A^2+C^2)]-A\times\log[(A^2+B^2)/(A^2+1)]-A\tan^{-1}(A/C)+2(A+B)\tan^{-1}(A/B)-2\tan^{-1}A-\pi\times(0.5A+B-1)] \quad (10)$$

Inasmuch as a, b, c, A, B, C, and k are dimensionless, we note that in calculating these quantities x, y, and D may be measured in any unit of length; but otherwise the units of all quantities mentioned to this point are in the absolute system: x, y, and D in centimeters; the current I in abamperes; L in abhenrys per centimeter of bus length; W in ergs per centimeter of bus length; F in dynes per centimeter of bus length.

Inasmuch as in actual practice the dimensions x, y, and D commonly are stated in inches, the current I in amperes, and the force F in pounds per foot, it is convenient re numerical computation to have an equation equivalent to equation 6 wherein, however, the various quantities are measured in the units just stated. Accordingly, introducing the necessary conversion factors in equation 6, we obtain

$$F=(5.4kI^2/D)10^{-7} \text{ pounds per foot of bus length} \quad (11)$$

wherein k, as before, is given by equations 7, 8, 9, or 10.

Regarding these formulas for k, we may remark that though each involves calculation of the sum of a number of logarithmic and arctangent terms—six in all—the actual labor required is not heavy. Thus, using the 15-place tables of natural logarithms and arctangents (with 0.0001 and 0.001 increment arguments) published by the Work Projects Administration[16] and effecting numerical calculations on a ten-digit electric calculating machine, the writer was able to effect the computation pertinent to the following illustrative example in but a few minutes.

An Illustrative Example

The conductors of a single-phase bus are standard aluminum channels (web, $y=8$ inches; flange width, $x=2.56$ inches; thickness 0.524 inches) spaced back to back, $D=16$ inches. To calculate k:

By virtue of the given data we have: $a=2$, $b=2.34$, and $c=2.64$. Substituting these values in equation 8 and performing the indicated calculation yields

$$k=-(1/0.6724)[\log 3.4715578-2.32\times\log 1.6169046-\log 1.27648-\tan^{-1}2.64+6.64\tan^{-1}2.32-4\tan^{-1}2-0.82\pi]$$
$$=-(1/0.6724)[1.2446034-2.32\times(0.4805136)-0.2441063-1.2087089+6.64(1.1638255)-4(1.1071487)-0.82(3.1415927)]$$
$$=-(1/0.6724)[-0.5999026]$$
$$=0.892+$$

Alternatively, $A=0.5$, $B=1.16$, and $C=1.32$. Substituting these values in equation 9 and performing the indicated calculation yields

$$k=-(1/0.3362)[0.5\log 3.4715578-1.16\times\log 1.6169046-0.5\log 1.27648+0.5\tan^{-1}0.3780303-3.32\times\tan^{-1}0.431034+2\tan^{-1}0.5]$$
$$=0.892+$$

Obviously, since it is only desired to know k to two or at the most three decimal places, it is not necessary to use seven-place logarithms and arctangents. Inasmuch, however, as 15-place tables were employed and the calculation was done on a ten-digit calculating machine, the added labor is negligible, and one has no uncertainty as to the effect of cumulative errors on the accuracy of the first few digits of k.

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The Nature of Vibration in Electric Machinery

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Synopsis: Vibration in electric machinery is the result of a number of contributing agencies, some mechanical, others electromagnetic in origin. Features of mechanical and electrical design and construction which give rise to these agencies are discussed. The general character of the vibration which each agency produces is explained, as well as how different agencies combine to produce the resultant machine vibration. Where excessive vibration is encountered in the field, methods are outlined for ascertaining the major agencies responsible so that corrective modifications may be made which will be effective in reducing the resultant vibration. These methods are applied to motor-generator sets driven by two-pole induction motors to ascertain the cause of a particular type of vibration characterized by the vibration amplitude increasing and decreasing in uniform cycles twice during each revolution of motor slip. In this way the agencies which give rise to this particular type of vibration are explained, and methods by which they may be controlled to keep the resultant vibration to a satisfactory minimum are discussed.

DURING the past few years the progress made in reducing vibration in electric machinery has resulted in more freedom from mechanical failures and other maintenance troubles. The more quiet machines which result from reduced vibration also produce less nervous strain to the operators. The generally accepted theory of vibration is based on the premise that vibration and noise arise from forces which act in a periodic manner upon the different component parts of the machine. Such forces are called "driving forces," and the actual mechanical displacement or vibration which results is frequently called the "vibrational response." The amplitude of the vibrational response depends upon the amplitude of the driving forces as well as upon the mass, stiffness, and damping factors associated with the vibrating member. While this fundamental concept is quite simple, yet to account for particular types of vibration which are produced in electrical equipment and mechanical rotating assemblies is sometimes quite difficult.

In general, the amplitude of a vibrational response can be reduced either by decreasing the amplitude of the driving forces which cause it, or else by modifying the mass, stiffness, and damping factors associated with the vibrating member so that a smaller response occurs under the action of the same driving forces. In electric machinery there are many agencies which contribute to these factors and to the final vibrational response. As a rule it is not a simple process to isolate the particular agencies responsible for excessive vibration, particularly when several agencies are cumulative in effect and are present simultaneously. A careful systematic study based upon a knowledge of conditions which are conducive to excessive vibration and the frequency components which arise from them usually is necessary before effective corrective measures can be specified.

The driving forces which are present in electric machinery are of two general kinds, namely, mechanical and electromagnetic. Mechanical driving forces are those which arise from mechanical or structural irregularities such as mechanical unbalance, nonsymmetrical mechanical parts, friction, loose bearings, and so forth. Electromagnetic driving forces are those which arise by virtue of magnetostriction and magnetic attraction between different parts of the machine. In any electric machine both kinds of driving forces are present simultaneously and act together to produce the vibrational response.

A very important agency which contributes to excessive vibration is static or dynamic unbalance of a rotating assembly. This produces an excessive mechanical driving force of fundamental frequency—that is, numerically equal to the speed of rotation in revolutions per second—and this results in an excessive vibrational response of the same frequency. This phenomenon has long been realized and many kinds of balancing machines, some of which are quite elaborate, have been developed for testing and correcting the condition of balance of rotating parts. For this reason this factor is not considered in detail here. It is mentioned merely because other types of vibration which arise from altogether different agencies frequently are attributed to improper balance. Mechanical unbalance alone always gives rise to a vibrational response having a frequency which is numerically equal to the speed of rotation in revolutions per second. This fact very often can be used to differentiate between excessive vibration due to mechanical unbalance and excessive vibration due to other agencies. Components of vibration having frequencies which are multiples of the speed of rotation in revolutions per second cannot be reduced appreciably by improvement in the conditions of balance of rotating parts, because the driving forces which produce them originate through other agencies.

Another well-known cause of excessive vibration which must be dealt with in machine designs is closely related to mechanical resonance in the rotating assembly and is referred to as the phenomenon of ordinary critical speeds. When the speed of rotation is such that the frequency of the driving force due to mechanical unbalance corresponds with one of the natural resonant frequencies of the rotating assembly, the latter is in indifferent equilibrium, and a small component of driving force may cause excessive vibration and whipping, or even mechanical failure, of the rotating assembly. For satisfactory operation the ordinary critical speeds must be consider-

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ably outside the normal operating speed range of the machine. This subject has received careful attention by many investigators who have developed methods whereby the critical speeds may be computed from the dimensions and component masses of the assembly.

Mechanical Driving Forces

The fundamental component of driving force which arises from a rotating assembly is caused by static or dynamic unbalance. It has a frequency numerically equal to the speed of rotation in revolutions per second. The amplitude of this driving force may be controlled by careful adjustment of balance of the rotating parts. In addition to the fundamental component, harmonic driving forces having frequencies which are multiples of the speed of rotation in revolutions per second frequently occur. These are caused by mechanical imperfections or dissymmetries in the construction of the machine. For this reason they are more difficult to control than the fundamental. The second harmonic component—that is the one having a frequency double that of the fundamental—is most likely to give rise to troublesome vibration. This component arises from shafts having portions of noncircular cross-sectional area, caused by keyways, for instance, from slightly elliptic bearings, as well as from other mechanical imperfections. Elliptic bearings are more likely to be a source of trouble in the case of ball bearings as avoidance of slight warping of the bearing races is practically impossible during the heat-treatment processes necessary in their manufacture. Slightly oval or nonspherical balls also may cause harmonic driving forces; but these are usually of higher harmonic order than the second and are not necessarily integral multiples of the fundamental. The only effective method by which harmonic driving forces arising from these causes may be controlled is by the use of rotating assemblies and shaft designs which are as nearly circular in cross section as practical considerations will permit, and by better workmanship and closer tolerances in the manufacture of the component parts of the machine. Harmonic driving forces must be given special consideration from the standpoint of vibration and noise in machines of special design where the rotating assembly is unusually long if the shaft has a keyway or other dissymmetries. They may be serious also if the inherent resonant frequencies of the machine frame correspond closely with the frequency of the harmonic driving forces.

Electromagnetic Driving Forces

Electromagnetic driving forces arise in electric machinery for several reasons, but the principal fundamental causes may be traced to magnetostriction and magnetic attraction between different parts of the magnetic circuit of the machine. Magnetostriction plays an important role in creating vibration and noise in static apparatus such as transformers. In rotating machinery the forces caused by magnetic attraction are by far the more important. In general these forces are quite complex in nature, consisting of numerous harmonic components. The frequency of the most important component, at least with respect to amplitude, is twice the frequency of the voltage at the machine terminals, and for this reason will be called the second harmonic component of electromagnetic driving force. Other harmonic components of driving force arise because of the slots in the stator and rotor of the machine. The

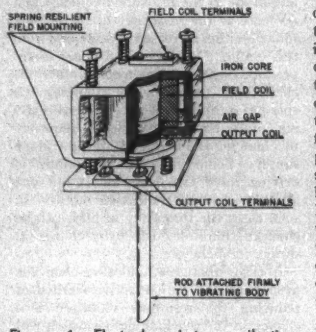

Figure 1. Electrodynamic-type vibration pickup unit

order of these harmonic components is a function of the number of slots on both the stator and the rotor. Certain of these are attributed to the machine windings not being infinitely distributed, while others exist simply because of the stator and rotor teeth. Certain combinations of stator and rotor slots result in much more pronounced driving forces than do others, and methods have been developed for choosing the optimum combinations for minimum noise. As a rule these harmonic components are of comparatively high order and are of importance in vibration principally from the standpoint of noise.

The second-harmonic component of electromagnetic driving force always is present in an electric machine. It arises principally from the radial magnetic attraction between the stator and rotor. Nearly all rotating machines make use of revolving magnetic fields. As the magnetic field revolves in the air gap of the machine, it passes a given point of the stator twice during each cycle of voltage change, once as a flux entering the stator and once as a flux entering the rotor. A force of attraction results regardless of the flux polarity. This force therefore builds up and dies away twice during each cycle of voltage change and produces a driving force having a frequency exactly twice that of the voltage supply. This driving force causes a periodic distortion of the stator core which, through the agency of the stator mounting supports, acts as a driving force to excite vibrations in the frame of the machine. This driving force cannot be eliminated since it is inherent in any electric machine, but the vibration or response it causes can be controlled by constructing the stator core sturdy enough so that the resultant core response is small, or in special cases such as large alternators (15,000 kva and larger) by mounting the stator core on flexible supports so that minimum vibration is transmitted to the frame of the machine.

The second-harmonic component of driving force is much more pronounced in two-pole machines than in machines having a greater number of poles, because the distance along the stator periphery between points where the flux is simultaneously at maximum values is comparatively much greater. This is one of the fundamental reasons why two-pole motors present more difficult problems from the standpoint of vibration than do motors having a greater number of poles. Forces of magnetic attraction act simultaneously upon diametrically opposite points of the stator and cause it to become distorted into an elliptic form, the distortion progressing around the stator in synchronism with the magnetic field.

In addition to the factors already mentioned, harmonic driving forces result from air-gap dissymmetries. The type of dissymmetry most frequently encountered is imperfect centering of the rotor in the stator core. This gives rise to a second-harmonic electromagnetic driving force in a two-pole machine. As the magnetic flux in the air gap revolves, it passes the point where the air gap is shortest twice during each cycle of voltage change, once as a flux entering the rotor and once as a flux entering the stator. Simultaneously, a flux of opposite polarity exists in the air gap at the point diametrically opposite. Since the radial magnetic force exerted on the rotor increases as the air-gap length decreases, the two attractive forces acting at diametrically opposite points of the rotor do not always cancel. When the flux is in the position where the air gap is longest or shortest, a net force results which acts toward the point where the gap is shortest. As the air-gap flux moves from the position, the unbalance between the two diametrically opposite forces diminishes and becomes zero at the point 90 degrees from this position. As the flux rotates further, an unbalance again exists in the same direction and reaches a maximum when the flux has moved through another 90 degrees. This unbalance of radial forces builds up and dies away twice

during each cycle of voltage change and produces a second-harmonic driving force which acts to deflect the rotor toward the point where the air gap is shortest. This driving force is transmitted through the bearing supports and serves as a driving force to produce vibrations in the frame of the machine.

This driving force may be eliminated by perfect centering of the rotor within the stator core. It also may be used in some instances to counteract or neutralize driving forces of the same frequency which arise from other causes, since the phase and magnitude of the driving force thus produced can be controlled by the use of an adjustable bearing support which will allow the rotor to be shifted off center in any desired direction. The magnitude of this driving force depends upon the amount by which the rotor is off center with respect to the stator, and the phase (with respect to the impressed voltage) depends upon which direction it is off center, that is, upon the angular position of the point in the air-gap periphery where the gap is shortest.

The use of this method for controlling vibration has several disadvantages from the standpoint of actual practice. Each machine of a like series must be adjusted independently to secure the maximum benefit. Also, if the machine is at all critical with respect to its mounting, an adjustment correctly made at the factory or for one location in service would not be correct for any other location or mounting. This method can be used to advantage, however, in emergencies and other instances where a better method cannot be readily applied.

Combined Effect of Electromagnetic and Mechanical Driving Forces

During the operation of an electric machine, the vibration or response which results from several driving forces may be considered from the standpoint of superposition. Each harmonic component of driving force will produce a component of response of the same frequency as that of the driving force. The amplitude of each component of the response depends upon the magnitude of the driving force and upon the mass, stiffness, and damping factors associated with the component parts of the machine. The resultant total response at any point of the frame is equal to the sum of the harmonic components of the response. If there is a correspondence in frequency between one or more of the driving forces and the natural or resonant frequencies of the component parts or complete assembly of the machine, comparatively large amplitudes of vibration will result, consisting principally of frequencies for these particular modes of vibration.

As a rule, excessive vibration due to resonance can be recognized by the behavior of the vibration accompanying changes in frequency of the driving forces. In the neighborhood of resonance, the vibration will build up to a maximum amplitude at the resonant frequency and decrease as the frequency of the driving forces is either increased or decreased from this value. Mechanical driving forces produced by a rotating assembly may be changed in frequency by changing the speed of rotation. Electromagnetic driving forces may be changed in frequency by changing the frequency of the voltage supply. Sometimes the two kinds of driving force are dependent upon one another as in the induction motor. In such cases the frequency of both can be changed simultaneously by a change in supply frequency.

In cases where mechanical resonance is prominent, the only effective method of reducing the resultant vibration is a change in the machine design which will shift the natural resonant frequencies inherent in the machine assembly outside the range of frequencies encountered during normal operation so that mechanical resonance will not occur. To insure this result in a new design is not easy because the geometric shapes of machine frames and other parts do not lend themselves to accurate mathematical analysis. It is very difficult, except in special cases, to compute the natural resonant frequencies of a machine frame or assembly. The final test of a design is the nature of the vibrational response which results under the action of the driving forces present under normal operation of the completed machine. If high amplitudes of vibration do not arise from small driving forces, the design is satisfactory. Otherwise stiffening of certain parts and modifications in the shape of others are necessary. Additional stiffness may be secured by increasing the size of the members, or by the use of cross braces of one form or another which increase the rigidity. The use of steel of higher tensile strength will have little or no effect, since the stiffness depends upon the modulus of elasticity which is essentially the same for all grades of steel regardless of the ultimate tensile strength.

From the standpoint of excessive vibration which results in excessive bearing wear, failure of mechanical members, and other maintenance troubles, as contrasted with noise, frequencies in the lower audio range are of major importance. For the lower resonant frequencies the stiffness and damping factors of mechanical members are comparatively much smaller, and a much greater resonant response can result. Fortunately, very low resonant frequencies are not usually encountered in actual practice in machines of standard design, because the frame and other parts must be constructed with sufficient strength to withstand stresses which are likely to arise during both normal and abnormal conditions of operation. For this reason the natural resonant frequencies inherent in the assembly usually will be of comparatively high order as compared with the driving forces produced by the machine in operation. Exceptions to this general rule occur in very large machines, and in compact high-speed motor-generator sets having comparatively long armatures. This is particularly true in machines of fabricated-steel-frame construction. In this latter instance considerable rigidity is sacrificed for the lighter construction thus

Figure 2. Vibration of motor generator set under load with voltage at rated frequency applied to the motor

A. Actual vibration as recorded by means of electrodynamic vibration pickup unit

B. Same as A except high-frequency components filtered out of recorded wave

Figure 3. Vibration of motor generator set coasting to rest without load and without generator excitation

afforded, and the lowest natural frequency may be of the order of 120 cycles per second or even less.

In the case of two-pole 60-cycle induction motors, the important electromagnetic driving force of lowest frequency is 120 cycles per second. At the same time a mechanical driving force, the second harmonic component, which has a frequency double the speed of rotation in revolutions per second, can exist. When these two driving forces exist simultaneously, they alternately reinforce and interfere with each other and cause a response which builds up and dies away in amplitude giving rise to the phenomenon of beats. Since the difference in frequency is exactly twice the slip frequency of the induction motor, two cycles of the beat frequency correspond exactly with one revolution of motor slip. If the lowest resonant frequency of the machine frame is in the neighborhood of 120 cycles per second, the vibration amplitude may build up to an excessively high value even though the driving forces are comparatively small. The beats are then very pronounced and clearly audible. The only effective manner of reducing vibration in this case is to modify the machine frame to avoid mechanical resonance, and perhaps also to modify the machine construction to reduce the amplitude of the driving forces. If the machine is of a portable nature such that the method of mounting or arrangement of support on its foundation may be changed, or if the machine operates over a fairly large speed range, the frame would have to be made more rigid, rather than less rigid, in order to avoid possible operation in the resonant range. Increasing the rigidity has the effect of raising the resonant frequencies. Appreciable increase in rigidity cannot be obtained by the use of the same frame design and steel of higher tensile strength. Frame members of higher moment-of-inertia cross section must be used.

Experimental Studies and Observations

The ideas presented in this paper are the result of considerable research which has been conducted on motor-generator sets in which the complete rotor assembly of both motor and generator was mounted on a single shaft supported by two ball bearings, one at either end of the shaft. The complete set was housed by a single fabricated steel frame of welded construction. The driving motor was a 3,600-rpm two-pole squirrel-cage induction motor. The particular type of vibration produced in these sets was characterized by the amplitude of the vibration building up and dying away twice during each cycle of motor slip, thus producing a very decided beat which was clearly audible. The beat is clearly distinguishable in most of the oscillograms of the accompanying figures which were obtained by means of an electrodynamic vibration pickup unit. The signals so obtained were amplified by one stage of voltage amplification, followed by a push-pull power-amplifier stage, the output of which was recorded by means of a mechanical oscillograph.

Figure 1 is a pictorial drawing of the pickup unit. The field coil was excited with direct current to produce a flux in the air gap in which the small output coil was mounted. The field coil and its associated magnetic circuit were supported on comparatively weak springs to allow free motion between this assembly and the output coil. The small frame which carried the output coil was rigidly attached to or else firmly held against the mechanical member when the vibration of the member was being recorded. The principle of operation of the pickup unit is similar to that of the dynamic type microphone, except that it is mass controlled. The electromotive force generated in the output coil is proportional to the relative velocity of this coil with respect to the field-coil magnetic circuit. The output wave form represents the instantaneous velocity of the vibrating member.

The actual mechanical displacement can be obtained from the velocity wave by taking the derivative, or else by resolving the wave into its sinusoidal components, dividing each component by its own angular frequency, combining the resultant terms, and interpreting the wave to the proper scale. As far as actual mechanical displacement is concerned, the velocity wave accentuates the high frequencies. If the noise produced by a machine is the factor of principal concern, the instantaneous sound pressure is more closely related to the instantaneous acceleration. The acceleration wave may be obtained from the velocity wave by one step of integration, or else by taking the sinusoidal components of the velocity wave, multiplying each by its own angular frequency, combining the resultant terms, and interpreting the resultant wave to the proper scale. The velocity wave represents an average of two extremes, and thus forms a good basis for comparing relative vibration amplitudes. It may be used very satisfactorily in studying the effects of different factors on the amplitude and nature of the vibration produced in a machine.

In order to eliminate the effects of stray electromagnetic fields which were very prominent in the proximity of the machines used in this investigation, the vibration pickup unit and the amplifier had to be very carefully shielded, both electrostatically and electromagnetically. The power amplifier stage was of the transformer input type and presented a difficult problem from this standpoint, because of the transformer connected to the grids of the output tubes. To reduce stray pickup from this source to a negligible value, the transformer was enclosed in a $^{3}/_{16}$-inch-thick soft-steel shield, and the amplifier was placed several feet from the machine under test.

Figure 2A is a representative oscillogram of the actual vibration which was obtained by the use of this apparatus. Careful examination of the pattern shows that the wave consists principally of a component of slightly less than 120 cycles per second which varies in amplitude having two maximum and two minimum values for each revolution of slip of the induction motor. In addition, the wave contains numerous harmonic components, some of rather high order, which are of fairly constant amplitude and bear no apparent relationship to the slip of the motor. The frequency of several of these harmonic components was measured with a sound analyzer and found to check with the frequencies to be

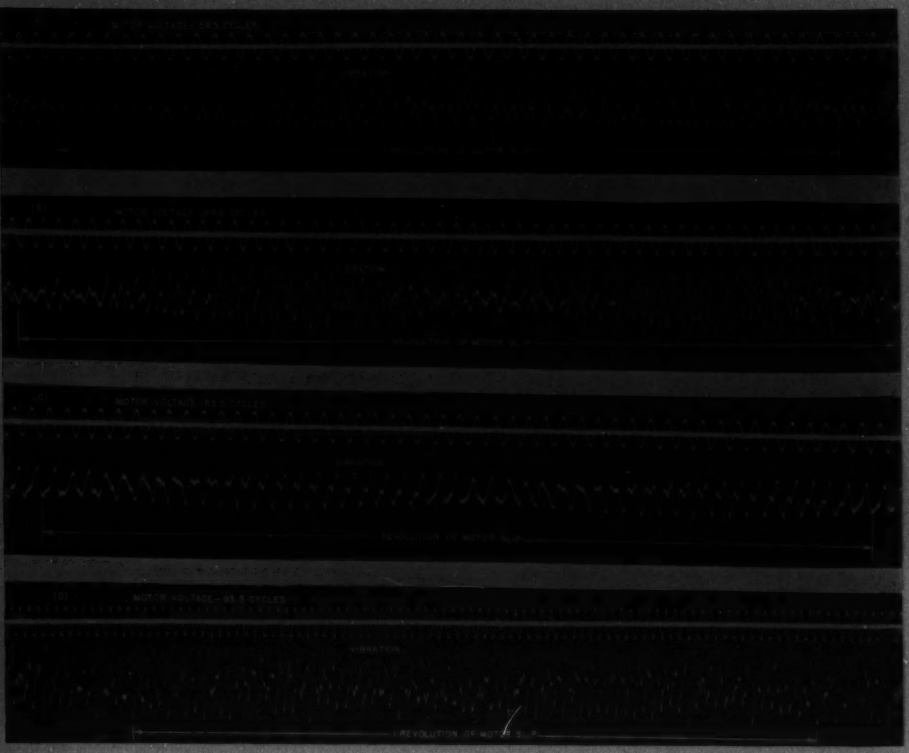

Figure 4. Oscillograms showing the effect upon the machine vibration of simultaneous changes in the motor supply frequency and speed

A. Machine speed 3,400 rpm
B. Machine speed 3,800 rpm
C. Machine speed 3,900 rpm
D. Machine speed 5,000 rpm

For comparing vibration amplitude of D with amplitudes of A, B, and C, divide by two

expected from the stator and rotor teeth of the machine. For these reasons, a capacitor was connected across the output terminals of the voltage amplifier stage to by-pass the high-frequency components and filter them out of the recorded wave. Figure 2B is an oscillogram of the same vibration recorded in Figure 2A, but with the filter capacitor connected into the amplifier circuit. Beats in this oscillogram are very pronounced, showing that the wave contains two principal components of approximately equal amplitude. By analysis, the frequency of one component is exactly 120 cycles per second, and the frequency of the other is exactly double the speed of rotation of the motor in revolutions per second.

The presence of the 120-cycle component of vibration is easily explained on the basis of electromagnetic driving forces produced in the machine as previously described. The component having a frequency twice the speed of the motor is due to mechanical causes only. This is shown clearly by the oscillogram of Figure 3. This oscillogram was obtained by starting the motor without load and allowing it to reach maximum no-load speed. Then the motor voltage supply was switched off and the machine allowed to coast to rest without load and without electrical excitation of any kind. The vibration was recorded while the machine was coasting to rest. The mechanical vibration has a maximum amplitude at approximately 3,580 rpm and contains a very large second harmonic component. This component decreases in amplitude quite markedly as the speed decreases, and becomes negligible at approximately 3,300 rpm.

That the beat vibration reached a high amplitude because of mechanical resonance is demonstrated by the following test. The motor of the set was supplied from an adjustable frequency source and operated at different speeds by adjustment of the source frequency. The beat would become discernible when the speed was approximately 3,300 rpm, increase in intensity with an increase of speed above this value, and reach a maximum intensity at approximately 3,560 rpm. As the speed was increased further, the beat would come less prominent, and would be barely discernible at 3,900 rpm. It was completely absent at 5,000 rpm. This behavior is illustrated by the oscillograms of Figure 4, together with that of Figure 2B. These oscillograms were obtained at speeds of 3,400 rpm, 3,800 rpm, 3,900 rpm, 5,000 rpm, and 3,530 rpm, respectively. For a comparison of relative amplitudes in Figure 4, the ordinates of oscillogram D are to be divided by two, since this oscillogram was obtained with the oscillograph adjusted for double the sensitivity used for recording the other three.

To ascertain the part of the machine responsible for resonance, the rotor assembly first was examined critically. The first ordinary critical speed was computed analytically by several methods from the

dimensions and masses of the rotor assembly. Different methods gave values ranging from 5,500 rpm to 6,200 rpm. As a final check, the rotor assembly was removed from the machine and mounted on rigid supports at the bearings. The natural frequency of vibration of the rotor assembly was measured by recording the free vibration of the rotor assembly under impact. Figure 5 is an oscillogram of the vibration at the center of the rotor assembly caused by a light blow from a rubber hammer. The blow was applied at the quarter-point of the rotor assembly. The frequency of the free vibration is 104 cycles per second, which corresponds with a first ordinary critical speed of 6,240 rpm. In actual operation of this machine, the bearings were not rigidly supported. This lack of complete rigidity somewhat lowered the critical speeds. By observation, the secondary critical speed due to gravity actually occurred between 2,800 and 2,900 rpm, which would fix the first ordinary critical speed at approximately 5,700 rpm. With the first ordinary critical speed of the rotor in this speed range, it is impossible to attribute the resonance phenomenon which occurred at 3,560 rpm to any resonant condition in the rotor assembly.

Impact tests similar to those described above were made to determine resonant frequencies in the machine frame. The complete frame, which was rectangular in shape, was mounted on three rigid point supports which could be moved to different relative positions. Blows were applied at different points of the frame, with and without the rotor assembly in place; and the vibration resulting at various points of the machine was recorded and studied. The nature of the free vibration depended upon the relative location of the three fixed point supports, the point where the blow was applied, and the point where the vibration was recorded. It made no apparent difference whether the rotor was in place or removed. The oscillograms of Figure 6 and Figure 7 are typical of the results obtained. Figure 6 shows a very prominent 115-cycle component and Figure 7 a very prominent 125-cycle component. In obtaining the oscillogram of Figure 6, two of the three point supports were placed at extreme corners of the frame at one end of the machine, and the third point support was placed at the center of the opposite end. For Figure 7, symmetry of the supports with respect to the frame was maintained, but the supports were placed considerably closer together. The actual mounting of the machine corresponded to a condition intermediate between these two and gave a resonant frequency of approximately 119 cycles per second.

As a final check on considerations regarding the cause and nature of the beat vibration, the frame of the machine was stiffened by welding several pieces of angle iron to the frame. The machine was operated at rated voltage and frequency, and the vibration was studied under different conditions of motor load, and with various arrangements of the three rigid frame supports. After reinforcement of the frame, the beat was completely absent at many points of the frame regardless of the arrangement of the rigid frame supports. At other points the beat could be detected, but was not prominent. At points where the beat was most prominent, the vibration was similar in character to that of Figure 4C. At other points, the vibration consisted almost entirely of a component slightly less than 60 cycles per second, which was due to slight mechanical unbalance of the rotating assembly. That the beat vibration was produced by the combined effect of electromagnetic and mechanical driving forces and reached a high amplitude because of resonance in the frame is clearly indicated by these tests and observations.

Conclusions

Vibration and noise in electric machinery arise by virtue of both mechanical and electromagnetic driving forces which exist simultaneously during normal machine operation. The amplitude of the vibrational response which results depends upon the amplitude of the driving forces, and also upon the mass, stiffness, and damping factors of the component parts of the machine. To secure quiet operation and comparative freedom from vibration, all of these factors must be dealt with. When excessive vibration is present in a machine of a particular design, the factors or agencies which contribute most to this condition must be ascertained, and modifications in design and construction made to minimize them. Because of inherent design features, two-pole induction machines and high-speed motor generator sets present more difficult problems from the standpoint of vibration than do machines having a greater number of poles which operate at lower speeds. Certain mechanical and structural irregularities of the rotating assembly may produce harmonic driving forces, and in particular a mechanical driving force having a frequency which is double the speed of rotation in revolutions per second. This driving force, acting simultaneously with an electromagnetic driving force having a frequency double that of the voltage supply, causes a resultant vibrational response which builds up and dies away in amplitude twice during each revolution of motor slip. This "beat vibration" may be very troublesome, particularly if the frame of the machine has an inherent resonant frequency which is approximately double the frequency of the voltage supply. A beat vibration of this kind may be reduced by careful attention to mechanical irregularities which give rise to the second harmonic component of mechanical driving force, or, if resonance is a contributing factor, by modifying the frame of the machine so that resonance does not occur. The second-harmonic component of electromagnetic driving force is inherent in the machine and cannot be eliminated; but it may be reduced with respect to the frame by the use of a stiffer stator core, or by the use of a special stator mounting which will not transmit the core response to the frame in cases where such refinements are justified. Whenever excessive vibration is encountered in electric machinery, a compre-

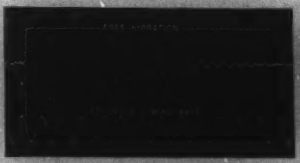

Figure 5. Free vibration of machine rotating assembly produced by a sudden blow from a rubber hammer

Assembly was mounted on rigid supports at the bearings

Figure 6. Free vibration of machine frame produced by a sudden blow from a rubber hammer

Frame was supported by three rigid point supports, one at each corner of one end of the frame, and one at the center of the opposite end of the frame

Figure 7. Free vibration of machine frame produced by a sudden blow from a rubber hammer

Frame was supported by three rigid point supports, two near one end of the frame, and the third near the opposite end of the frame

hensive study based upon a consideration of the frequency of the components of vibration present and the agencies which give rise to them will point the way to proper corrective measures and modifications which will be effective in reducing the resultant vibration.

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Electrothermal Space Heating and Air Conditioning

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SPACE heating of dwellings has been one of the prime necessities in the improved living conditions of the human race and one that has received considerable study from the earliest time. As the various heating methods were developed, from the early open fireplace to modern heating equipment, utility and esthetic designs for the heating equipment were given a great deal of consideration.

In Sweden very artistic heating units were developed approximately 150 years ago of ceramic glazed tile, which were extremely attractive in design as well as being useful. These devices used small quantities of fuel to heat the entire mass of tile, and the heat energy stored in this tile was radiated into the room, furnishing the required heat for the day.

In the last 20 years in the Pacific Northwest, experiments have been conducted continually, and many practical installations which utilize electric energy for heating have been made. However, these installations have been almost entirely of the radiant and convection type of heater. This type of heater requires an uninterrupted supply of electric energy. In 1935 at the city of Grand Coulee, adjacent to Grand Coulee Dam, an electric heat-storage installation was constructed and placed in operation utilizing granite boulders for the heat-storage medium. This installation was operated for approximately two years on an experimental basis, the results of which experiment were outlined fully in a report by the State College of Washington experiment station.[1] Also in the Pacific Northwest, several installations of storage heaters utilizing hot water are in operation with varying degrees of success.

The problem of filling valleys and reducing peaks in daily load curves of utility systems has existed since the early days of electric distribution. Daily load factor has a direct bearing on cost of service. Increasing load factor decreases cost of service. Incentive rates have been established by utilities in order to encourage use of electric service during off-peak hours, as witnessed by special rates established for hot-water heating and the development of devices for controlling use of electricity during predetermined hours. The present-day prices charged for electric energy used by consumers in the Pacific Northwest are low enough to have encouraged serious consideration of the adoption of electric space heating.

The increased cost of oil, coal, and wood fuels, and the severe curtailment of oil is an incentive for the use of electric energy in space heating.

These conditions led the author to consider the development of a method for utilizing an electric-energy–heat-storage system which would permit the use of off-peak electric energy obtained principally during the night hours

In designing the electrothermal storage system for space heating, consideration was given not only to the heating but also to the problem of air conditioning in as simple a manner as possible, bearing in mind that the electrical method was the one offering the greatest possibilities for regions having low-cost hydroelectric energy as available in the Pacific Northwest. Cleanliness was also a prime factor to be considered. It was decided that a medium for heat storage should be selected which offered extreme flexibility and provided for the storage of a large amount of heat energy in the minimum of space. Water under moderate pressures and temperatures seems to offer the best solution to this problem. Therefore, a system was devised wherein water is stored in an unfired pressure vessel under a pressure of 200 pounds per square inch and at the saturated temperature corresponding to this pressure. Electrothermal space heating is based on fundamental thermodynamic principles, when a common fluid (water) is used for the storage of heat generated by electric energy. The heat is stored in the fluid under pressure. As the pressure is reduced, the sensible heat of the fluid is converted into latent heat of vaporization. The vapor carries this heat to the heat exchanger and liberates the latent heat when condensation takes place.

By the use of this method of off-peak heat-energy storage, economical use of a utility's distribution system can be accomplished. The present distribution systems of the various utilities are being

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utilized at a relatively low load factor. Greater use of these facilities during the periods when the load factor is low permits the fullest possible use of the system with only minor expansion of the distribution facilities. Any added use of these facilities is a source of additional revenue to the utility with only slight additional cost. Another very important factor of the off-peak storage system is that it does not require the utility to guarantee uninterrupted service. This factor has caused the utilities in general to back away from space-heating loads, because additional equipment is required on their part to render this uninterrupted service. Normal outages in no way would affect the heating of the dwelling, if the storage system is in use. As a general thing, the rate structure of a utility is set up to carry all fixed charges and operating expenses plus a reasonable profit on the distribution of energy at a moderate load factor. Therefore, the additional energy distributed over their existing facilities without much additional cost to them is very desirable. The revenues derived from this additional energy will result in a greater net income, which in turn can be shared with the users of electric energy, thus benefiting both the utility and the user.

With reference to Figure 4, a typical daily load curve of the Pacific Power and Light Company (main system) for December 16, 1943, shows the night load between midnight and 6:30 a.m. to be less than half of the peak load during the evening hours from 5:00 p.m. to 7:00 p.m. On this load curve the morning peak between 8:00 a.m. and 12:00 noon is slightly lower than the two-hour peak between 5:00 p.m. and 7:00 p.m. However, some of the systems reverse this order and have a higher peak during the morning hours, but the duration of both morning and evening peaks are approximately as shown on this load curve. It is the object of the off-peak electrothermal heating system to use as much as possible of the available energy represented by the valleys in this curve for space-heating purposes. The shaded section above the load curve represents the energy that would be used by 100 homes similar to the one that was chosen as a demonstration unit at the Midway substation of the Bonneville Power Administration, which is located in the area of central Washington served by the Pacific Power and Light Company. It is estimated that the off-peak energy represented by the valleys of this load curve could be used to heat 1,500 five- or six-room dwellings.

The electrothermal off-peak heat-storage system was designed to meet all of the safety and insurance requirements of the state of Washington, the city of Seattle, and the city of Tacoma, as well as the code of the American Society of Mechanical Engineers for unfired pressure vessels. All electric equipment used in this system has been approved by the national Underwriters' Laboratories.

Principal Equipment of the Electrothermal Off-Peak Storage System

A general description of the electrothermal storage-space-heating and air-conditioning equipment consists of the following:

The main items of equipment are a superheated hot-water accumulator, immersion electric heaters providing the source of heat, a reducing valve for automatically releasing the heat energy from the accumulator to a lower pressure level, a heat-transfer element for transmitting the heat energy into the air used for heating the dwelling, a condensate receiver to store the condensate until such a time as it is returned to the accumulator, an electrically controlled feed pump, a thermostat for maintaining a constant predetermined temperature in the dwelling, a humidistat for maintaining the relative humidity at a predetermined level, renewable dust filters, activated carbon filters, and an air-circulating fan.

Method of Operation of Electrothermal Off-Peak Storage System for Winter Heating

A schematic diagram of the electrothermal off-peak accumulator system is shown in Figure 1. A description of the method of operation of this system is outlined here.

The accumulator *A* is an unfired pressure vessel filled 90 per cent full of water under normal operating conditions. When fully charged the pressure in the accumulator is maintained at 200 pounds per square inch and 388 degrees Fahrenheit. The accumulator is built according to the specifications of the latest unfired

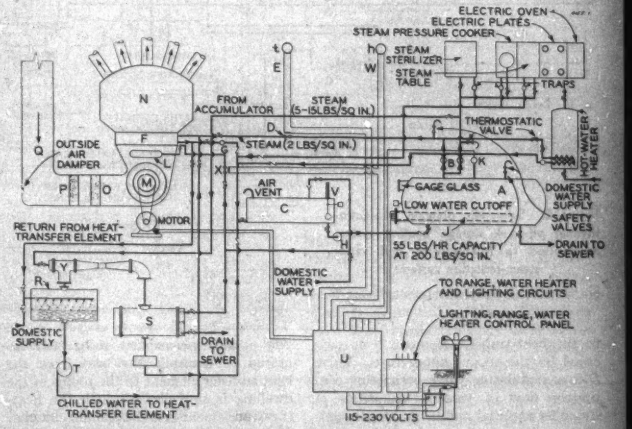

Figure 1. Schematic diagram of complete electrothermal off-peak accumulator heating and air-conditioning system

Equipment:

A. Electrically heated water tank and accumulator. Normal operating condition 90 per cent full
B. Steam-pressure reducing valve
C. Condensate receiver
D. Modulating thermostat control valve
E. Room thermostat and time clock
F. Heat-transfer element
G. Condensate return trap
H. Feed pump
J. Immersion electric heaters
K. Pressure control
L. Humidifier
M. Air fan
N. Plenum air chamber
O. Activated carbon filter for air purification
P. Removable air filter for dust
Q. Return air duct from rooms
R. Evaporator
S. Condenser
T. Chilled-water pump
U. Control panel
V. Float switch in condensate receiver
W. Room humidistat
X. Humidity-control valve
Y. Thermocompresser unit

Specifications:

All electrical controls to be Underwriters' approved standard. Accumulator to be approved ASME unfired pressure vessel for 200 pounds per square inch and 388 degrees Fahrenheit. Valves, fittings, and piping to be American standard for 200 pounds per square inch working steam pressure

pressure vessel Code as published by the ASME, which insures a pressure vessel having a high factor of safety for use in dwellings. The vapor above the water in the accumulator is released through a pressure-reducing valve B, which reduces the pressure from 200 to 2 pounds per square inch. The two-pound per square inch steam line is provided with a safety valve in order to limit the pressure in this part of the system to not more than five pounds per square inch. Thermostatic control valve D, which is under control of the room thermostat and night setback time clock E, regulates the flow of steam

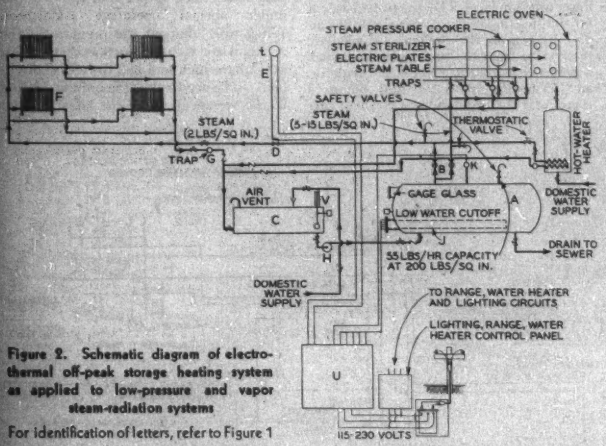

Figure 2. Schematic diagram of electrothermal off-peak storage heating system as applied to low-pressure and vapor steam-radiation systems

For identification of letters, refer to Figure 1

to the heat-transfer element F as governed by the room temperature. Valve D is a modulating valve permitting continuous flow of varying quantities of steam as required and is not the on-and-off type. As the steam is condensed in the heat-transfer element, the flow of condensate is controlled by a thermostatic trap G, which allows only the liquid to pass. The condensate is returned to the condensate receiver C, where it is stored until such a time as the liquid level has risen to a predetermined point. At this predetermined point the float switch V energizes the feed-pump circuit and permits the feed pump H to return the condensate to the accumulator A at the slow rate of approximately 0.25 gallon per minute. The condensate cannot be returned to the accumulator unless the heating elements J are energized. This low rate of feed to the accumulator was fixed, so that this water could absorb nearly all of the required heat energy from the immersion electric heaters, rather than deriving it from the high-temperature water in the accumulator. It is evident that with this closed circuit there will be little or no loss of water which would require an appreciable amount of make-up water. Because of the closed circuit there is no accumulation of solids from the water to form objectionable scale in the system. Safety features in connection with the hot-water accumulator are a safety valve with outside discharge, which has a steam-flow capacity considerably in excess of the heat-generating capability of the electric immersion heaters J, and an electric pressure control K which interrupts the power circuit to the electric heaters when the pressure in the accumulator has reached the predetermined pressure of 200 pounds per square inch. Air required to transmit the heat from the heat-transfer element to the rooms of the dwelling is propelled through the heat-transfer element into the plenum chamber N by the forced-air-circulating fan M. From this point air is conducted to the rooms of the dwelling by well-designed and well-constructed air ducts. The return air from the rooms is conducted through the return air ducts Q, and is passed through removable dust filters P, which remove all dust and lint from the air. This air then passes through activated carbon filters O, which remove all household odors. Outside air is admitted to the suction side of the fan in sufficient quantities only to maintain the oxygen and the carbon-dioxide contents of the air at normal levels. By recirculating the air in the system, with only this small addition of outside air, considerable heat is saved, and a slight positive pressure inside is maintained, thus reducing infiltration of outside air. To maintain the proper relative humidity in the dwelling, a humidifier L is provided. The moisture for humidification is provided by a fine spray nozzle that injects the water into the air stream in the form of a mist. This mist then passes through the heat exchanger and is completely vaporized and mixed with the heated air. The flow of water to the spray nozzle is through valve X, which is under the control of room humidistat W. To govern the flow of electric energy to the system, time switches are provided to determine the point at which the energy is cut off during the peak period of the day and then re-established during the night hours. A second time switch is provided which will permit a limited amount of energy to be taken during the off-peak period between 12:00 noon and 5:00 p.m. The controls are operated so that the various heaters are energized in groups; therefore, the entire heater load cannot be thrown on the system at one time. This function is controlled by a motor-driven step controller which permits the energization of the first four kilowatts of heater capacity, then the next six kilowatts of heater capacity, and finally the last four kilowatts. Should the demand for heat during the day vary from the maximum, the step controller will reverse its direction of rotation and de-energize the heaters in steps in order that the predetermined pressure of 200 pounds per square inch in the accumulator will not be exceeded.

Method of Operation of Electrothermal Off-Peak Storage System for Summer Cooling

For summer cooling, the steam supply to and condensate supply from the heat-transfer element are shut off by the closing of valves in those lines, and the two valves controlling the chilled water to and from the heat-transfer element are open, and a summer switch governing the automatic controls is placed in the summer position. This automatically energizes the summer cooling equipment and controls. The cooling is accomplished by circulating chilled water through the heat-transfer element F. This chilled water is produced by the use of a small vacuum water-refrigerating unit which comprises a thermocompressor unit, condenser, and evaporator. The steam from the accumulator is utilized to operate the thermocompressor Y, which together with secondary steam-jet ejectors produces a vacuum in evaporator R. Return water from the heat-transfer element is sprayed into the evaporator, which operates at a high vacuum causing the evaporation of a portion of the return water. This evaporation removes the heat from the balance of the return water, reducing its temperature to approximately 45 degrees Fahrenheit. The water vapor evaporated, plus the steam supplied to the thermocompressor, is carried over to the condenser S, which is cooled by

circulating water from the domestic water supply. The condensate from the condenser is returned through a vacuum trap to the condensate receiver *C*, and thus re-enters the closed circuit to the accumulator. The chilled water from the bottom of the evaporator is circulated by a chilled water pump *T*. This pump is controlled by the room thermostat *E*, thus maintaining a temperature within the dwelling approximately 15 degrees Fahrenheit below the outside air temperature. As the entire system is controlled automatically, after being adjusted, it requires little attention for operation.

two pounds per square inch steam-discharge header from the hot-water accumulator to the main steam riser of the existing system. The main thermostat *E* will respond to the room temperature and regulate the steam flow through the modulating-thermostat-control valve *D*. By this method of control the steam flow to the radiators varies with the demand for heat as indicated by the thermostat. The condensate from the radiators is returned through the common drain header back to the condensate receiver *C* through the thermostatic trap *G*. Here again the system is a closed one, and the condensate

stalled. The various uses to be made of the steam in the kitchen and for hot-water heating remain as previously described.

Hot-Water Heating

Figure 3 shows the two general types of hot-water-heating systems that are installed in existing dwellings, namely, gravity systems and forced-circulation systems. The use of the electrothermal off-peak accumulator system with either type of the previously mentioned installations is practically as simple as that used in the low-pressure steam radiator

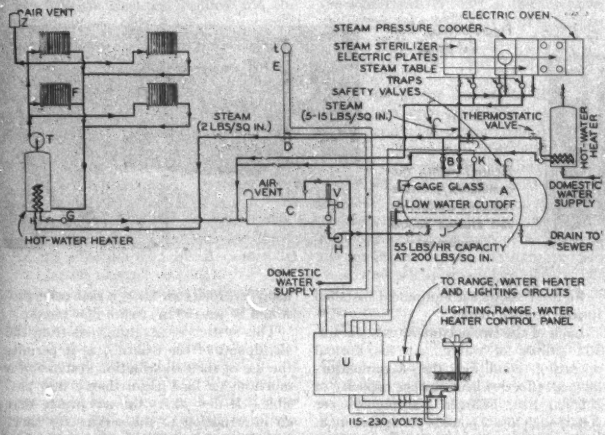

Figure 3. Schematic diagram of electrothermal off-peak storage heating system as applied to gravity and forced-circulation hot-water heating systems

Equipment:

A. Electrically heated water tank and accumulator. Normal operating condition 90 per cent full
B. Steam-pressure reducing valve
C. Condensate receiver
D. Modulating thermostat control valve
E. Room thermostat and time clock
F. Hot-water radiation
G. Condensate return trap
H. Feed pump
J. Immersion electric heaters
K. Pressure control
T. Hot-water pump, either forced or gravity circulation
U. Control panel
V. Float switch in condensate receiver
Z. Expansion tank

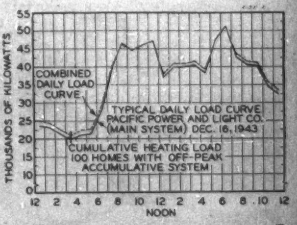

Figure 4. Typical daily load curve of a utility system

Effect of space-heating load on Pacific Power and Light Company. 100 homes—accumulator system

With an accumulator system of this kind in a dwelling, advantage can be taken of the stored heat energy to provide sterilizing steam for use in the kitchen, as well as to provide a source of steam-heat energy for pressure cooking of food and for a steam table to maintain prepared food at a uniform temperature, thus making available to the occupant of a small dwelling all of the conveniences that now are available in the most modern hotel and restaurant kitchens.

Low-Pressure Steam Installations

Figure 2 shows adaptability of the electrothermal heating system to existing dwellings having low-pressure steam-heating installations.

The electrothermal heating unit can be used as the source of heat energy for existing dwellings that have installations of low-pressure steam radiators *F* for heating. It is not considered necessary to repeat the description of the various elements in the electrothermal heating system, as these have been described earlier in this paper. In order to adapt the electrothermal storage heating system to a low-pressure steam-radiator installation, it is necessary only to connect the

is continually re-used with only slight make-up water being required. With this low-pressure steam-heating system, no control of relative humidity or air conditioning is possible unless additional ventilating ducts and equipment are in-

system. In order to adapt the electrothermal accumulator system to hot-water heating, it is necessary to provide only a small hot-water tank fitted with an immersion steam coil. This coil functions as a heat-transfer element to heat the water of the radiator system. The flow of steam to this immersion coil is controlled by the modulating thermostatic control valve *D*, which in turn is controlled by room thermostat *E*. The circulation in the gravity hot-water system is comparatively slow, which makes it difficult to maintain a uniform room temperature. If the hot-water system is of the forced-circulation type, a more even distribution of the water is obtained throughout the system, and the water temperature can be governed more uniformly by the thermostat. The hot-water

Figure 5. Chief operator's cottage at Midway substation

heating systems do not provide humidification nor air conditioning. In order to obtain these features it would be necessary to provide humidifying and ventilating equipment.

Midway Cottage Installation

An electrothermal off-peak heat-storage and air-conditioning system has been installed recently in a five-room cottage at the Midway substation of the Bonneville Power Administration in central Washington (see Figure 5).

The cottage has no basement. Therefore, to conserve space in the dwelling, the entire electrothermal and air-conditioning unit was installed in the attic.

The cottage is well-constructed with insulated floors, side walls, and ceilings. All windows are tightly weather-stripped, and both front and back entrances are vestibuled with double doors. The design conditions at Midway are minus five degrees Fahrenheit outside and 70 degrees Fahrenheit inside, with a computed heat loss for the dwelling of 35,000 Btu per hour.

All of the heating equipment is housed in a small well-insulated room constructed in the attic. This room is easily reached through a hatch from the utility room on the first floor.

The electric control board was placed on the outside wall of the small equipment room to make it accessible for testing purposes. This board is shown in Figure 6.

The cold air return duct system was installed under the floor, and the hot air ducts were placed over the ceiling joist. The hot air is distributed from the duct system through registers or grills placed near the ceiling line, affording a very even method of distribution of the air in the dwelling.

Two electrothermal hot-water accumulators were used in this installation instead of a single larger one in order to secure the required heat-storage capacity and yet be small enough to pass through a 24-inch by 24-inch hatch to the attic. The arrangement of the equipment in the room is compact yet accessible for maintenance purposes.

Hot-water accumulators are insulated with $4\frac{1}{2}$ inches of magnesia block and 4 inches of rock wool and then covered with duck which is pasted on.

The entire duct system is insulated with rock wool, which is wired on and finished by covering with duck.

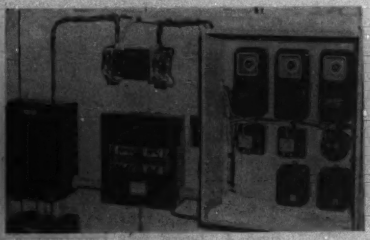

Figure 6 (left). Control panel

Figure 7 (right). Accumulators, pressure-reducing equipment, and electric control equipment

Figure 7 shows the equipment installed inside the attic room.

Each of the two accumulators contains 104 gallons of water. At the normal operating condition the accumulators have an effective heat-storage capacity of 300,000 Btu, between 200 pounds per square inch and 2 pounds per square inch.

The Midway installation incorporates all of the features discussed in connection with schematic diagram, Figure 1, with the exception of the refrigerating unit. This will be installed as soon as it is completed. Weather conditions have been too warm to obtain any scientific data on this heating system.

Conclusions

Electrothermal space heating and air conditioning is based on thermodynamic principles and is very simple. The equipment involved in the construction of the system is standard and can be supplied by existing manufacturers.

Heating and heat-storage features can replace oil, coal, or wood-burning equipment used in existing heating systems in dwellings, such as hot-air heating, Figure 1; low-pressure and vapor-steam heating, Figure 2; and gravity or forced-circulation hot-water systems, Figure 3. It is also possible to make use of the stored heat energy for sterilizers, pressure cooking, and steam tables, giving the housewife all the advantages of the modern hotel kitchen.

The system is practical and economical to install in any dwelling or building now existing or in new construction. It is estimated that the cost for converting a hot-air heating system to the electrothermal storage heating system in a six-room dwelling would not exceed $800.

The electrothermal heat-storage unit uses daily off-peak electric energy, thus using hydroelectric energy that otherwise would be wasted in stream-flow plants.

This system is advantageous from the standpoint of the utilities, as it permits the use of their distribution systems at a much higher load factor than is now possible. It also offers the advantage that an interruption to the service for short periods of time, which are unavoidable, has no effect on the operation of the storage system.

The consumer derives advantages from the storage system by being assured of a continuous heat supply. Then there are advantages of cleanliness, elimination of all fire hazards, lower insurance rates, simplicity of operation, and minimum space requirements.

Studies indicate that the cost of the equipment installed in the dwelling is moderate and competitive with other first-class heating and air-conditioning equipment on the market at the present time.

Reference

1. The Feasibility of Using a Heat Storage Device for Domestic Heating With Electricity, Homer J. Dana, R. E. Lyle. State College of Washington *Bulletin*, volume 18, July 1935.

An Investigation of the Relationship Between Temperature and Movement of Cables in Ducts

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MANY complex thermal and mechanical influences govern the relationship between electrical loading and the movement of cable in an underground conduit line. It is probable therefore that a knowledge of the relationship will come only through the analysis of many careful observations of the movement of cable in conduits of different types and in different locations and also under the influence of electrical loadings of various magnitudes and durations. It is apparent that engineers now appreciate the importance of a knowledge of the factors that influence cable movement as well as of the control of these factors as a requisite for higher loading of cables that operate under the load factors normally encountered.

This paper contributes to the general information that is accumulating on the subject the results of tests made over a five-month period in the underground distribution system in Buffalo, N. Y. It also describes the testing methods and the equipment used in the hope that this information will prove helpful to others who may wish to conduct similar tests. Finally the paper advances a theoretical explanation of the relationship between the electrical loading and the mechanical movement of cable. The test results support the theory, but more data are required for a confirmation. It is hoped that the presentation of this theory will stimulate the assembly of additional data.

Description of Conduits and Cables on Test

About 8,600 feet of 350,000-circular-mil 25-kv cable, located in a typical underground conduit line, was operated on a controlled-current loading schedule which permitted the recording of the expansion and the correlated sheath temperature rise over a period of about five months. The load cycle for most of the tests was equivalent to a load factor of less than 30 per cent, although some data were obtained for load factors approaching 100 per cent.

The site of the test was a 4,300-foot conduit run in an area considered typical of underground-system conditions in Buffalo. The conduit installation is less than 15 years old. It contains 16 four-inch fiber ducts installed in a concrete envelope with the individual ducts on seven-inch centers and arranged four ducts wide and four ducts high. Most of the manholes are ten feet long, six feet wide, and about seven feet deep. The entire line is located beneath asphalt street paving.

The general arrangement of the test conduit line is shown in plan and profile in Figure 1. There are 17 sections between manholes, and individual sections vary from less than 100 feet to over 400 feet in length. Some of the sections are in rock, whereas other sections are above the rock line. Some of the sections are submerged in ground water, some are what might be termed moist, and a few are relatively dry.

The conduit is not subjected to external heat influences and carries only three three-conductor 350,000-circular-mil, 25-kv cables all located in the bottom row of ducts. Two of these cables, in adjacent ducts, were used for the tests. The remaining cable carried no load while the test was in progress. The cables manufactured in 1930 have regular sector conductors which are insulated with $^{20}/_{64}$ inch of impregnated paper and shielded with three-mil-thick copper tape over the insulation. The insulated conductors are bound together with a five-mil-thick steel binder. The lead sheaths are $^{9}/_{64}$ inch thick. The complete cable has an over-all diameter of $2^{7}/_{8}$ inches and weighs about 12 pounds per foot.

These cables, installed in their present location in 1931, have attained sheath surface dullness and rest in the ducts in a normal fashion. They have never been loaded above a small fraction of their normal carrying capacity. They are arranged rather well in the manholes with the splices centrally located on hangers approximately 40 inches apart. The splicing sleeves are 28 inches long and $5^{1}/_{8}$ inches in diameter. The two cables included in the test are carried through the manholes on the same 17-inch arms. Radii of the bends in the manholes vary considerably but fall in the general classification of 15 inches at the duct mouth and 30 inches at the support arm with a total offset from the line of ducts of 18 inches.

Description of Test Equipment

The two test cables, located in adjacent ducts, were connected in series, and the three conductors were connected solidly together at one end of this test circuit. The power supply to the test circuit was provided through a three-phase low-voltage source with variable-voltage control, capable of providing up to 380 amperes per phase to the test cables. This maximum current produced roughly 18 watts loss per foot of cable.

Time-clock control was provided so that the test current was initiated and interrupted on a selected time schedule. The test-current magnitude, however, was manually preselected with the result that unit cable losses varied somewhat as the test-cable conductors heated up on each load cycle.

Cable-sheath temperature was measured by a special probe which fits into the same duct occupied by the cable. The probe is fitted with an "advance-copper" thermocouple which is carefully shaped to make a large-area contact when it is pressed against the cable sheath by the action of a bellows. The couple is mounted on a small bakelite plate which is attached rigidly to the formed end of a small-diameter steel pipe. A small metallic bellows is attached to the pipe probe on the side opposite the couple. Figure 2 shows the couple end of the probe.

The probe is inserted, couple end first, into the duct containing the cable to be checked. When the couple is in the duct six or seven feet from the manhole duct entrance, and contact between sheath and couple is evident from an electrical-continuity test between couple and cable sheath, a pressure of 15 pounds per square inch is applied to the bellows by way of the pipe probe. The bellows presses against the duct wall and forces the couple against and slightly into the cable sheath.

Sheath temperature is read by using the thermocouple in combination with a potentiometer which is compensated for ambient temperature. During the tests the temperature measurements were taken at intervals of roughly 30 minutes and always at the close of each test. Unattended recording equipment was not used because of the possibility of losing thermal contact with the cable as a result of cable expansion. However, the probe was left in the occupied duct between readings to reduce effect of thermal lag.

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Table I. Summary of Temperature

Curve	Date of Measurements (1943) From	To	Current in Amperes	Duration of Current in Hours	Manhole 145 (East) Sheath Temp—°C	Sheath Temp Rise—°C	Expansion in Mm	Manhole 171 West Sink Temp—°C	Max Sheath Temp—°C	Sheath Temp Rise—°C	Expansion in Mm	Manhole 171 East Sink Temp—°C	Sheath Temp—°C	Sheath Temp Rise—°C	Expansion in Mm	Manhole 205 West Sheath Temp—°C	Sheath Temp Rise—°C	Expansion in Mm	Manhole 205 East Sheath Temp—°C	Sheath Temp Rise—°C	Expansion in Mm
A	5-13	5-20	260	4	23	13	4.5	10	24.5	14.5	4.5	10	21.5	10.8	3.5	25.7	13.5	4.5	20	6.8	2.0
E	6-10	6-10	260	7			6.0				5.5				4.0			6.0			4.0
F	6-14	6-14	260	4			4.5				4.5				3.0			4.0			2.5
G	6-15	6-15	300	4			7.0				7.0				5.0			6.0			4.5
H	6-16	6-16	380	4			15.5				13.0				11.5			15.0			10.0
I	7-26	7-27	260	4			4.5				4.5				3.5			4.5	32.0	6.5	2.5
J	8-30	8-30	260	4																	
K	8-31	8-31	300	4			7.2				6.8				6.5			6.0			5.5
L	9- 1	9- 1	380	4			15.0				14.5				12.0			15.0			11.0
M	9- 7	9- 7	260	4			5.0				4.5				3.5			5.0			3.0
N	9- 8	9- 8	300	4			8.0				7.0				7.0			7.5			5.5
O	9- 9	9- 9	380	4			15.0				14.5				12.0			14.0			12.0
B	9-14	9-23	260	4	30	12	5.0	18.5	36	14	5.0	18.5	29.5	10.5	4.0	35.3	13.8	5.0	28.0	7.5	4.0
C	9-23	10- 1	325	72	48	29	16.0	17.5	51	32	16.5	17.5	44	25	15.0	51.0	30	14.5	38.2	15.7	12.0
D	10- 8	10-14	300	149	44	26	15.0	16.5	48.5	30	14.0	16.5	42	24	14.0	48.5	29	12.0	38.0	19.0	10.0

* Four to eight-watt-per-foot heaters in adjacent ducts in section from manhole 317 east to manhole 347 west from 9-7-43 to end of tests. Heaters on same time cycle as test cables.

A continuous record was made of the expansion and contraction of the test cables at the duct entrances in the manholes. This was accomplished through the installation of graphic recorders made up from old graphic demand instruments. A flexible shaft, attached to the cable at the duct edge, transmits cable motion to the recorder mechanism and pen and provides a continuous record of cable motion on paper strip charts. This arrangement of the recorder is shown in Figure 3.

Mercury-bulb thermometers were used to obtain sink and empty-duct temperatures. A small-diameter steel pipe about four feet long was driven through the manhole wall about four feet below grade and at right angles to the line of the conduit run to accommodate the thermometer for sink measurements. The locations at which sink temperatures were measured are shown in Figure 1.

Test Schedule

Before starting the tests, each manhole was carefully inspected, all subnormal arrangements of the cables were corrected, and all fireproofing was removed from the cables. The field survey was started by taking photographs of the interior of all of the manholes by means of special photographic equipment which fitted into the manhole-cover openings in such a way that all pictures taken of each manhole were from the same camera position and angle of exposure. This made possible a direct comparison of photographs to determine the changes in the positions of the cables, splices, supports, and so forth, and for correlation with field measurements taken during the tests. The advantage of this care in the photographic work is shown in Figure 4, where a picture taken during a severe load cycle is superimposed on one taken after the testing was completed. Figure 5 shows the photographic equipment itself.

Bending radii and location dimensions were taken to establish the position of the cables at the start of the tests. Current then was applied in two four-hour 260-ampere cycles each day. This loading, four hours on and eight hours off in each 12-hour period, was about double the 24-hour load factor for which ratings were desired, but at the low heating level no carry-over of heat between the individual cycles occurred. This loading developed about seven watts per circuit foot of cable.

Temperature observations during the first few load cycles showed appreciable increases in only six sections. Expansion recorders were installed on the 12 ends of these six sections. The balance of the conduit line was either quite moist or partly flooded.

With a few interruptions for spot checks, the test schedule of two 260-ampere four-hour cycles every day was continued from May 13 to August 11. From that date to September 26 the schedule was changed to one four-hour 260-ampere load cycle per 24-hour period. During this latter schedule special heating cables, each having losses of eight watts per foot, were installed in four ducts adjacent to the test cables in one of the sections which showed a large temperature rise during the earlier tests. The purpose was to simulate the effect of additional loaded cables in this section of conduit by the addition of losses equal to 32 watts per foot. The heating cables were energized and de-energized on the same schedule as the cables under test.

A few special tests were made at higher values of loading and some for longer durations in order to obtain data on the thermal characteristics of the conduit system. These data subsequently proved

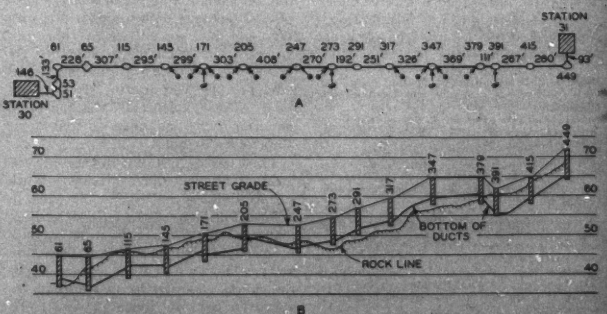

Figure 1. Plan and profile of the test conduit line

* Indicates location of sheath-temperature thermocouple and cable-expansion recorder

# Indicates location of earth temperature thermometers

Manhole 247						Manhole 273 (West)				Manhole 317 (East*)				Manhole 347								Manhole 379 (West)			
West			East											West*				East							
Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sink Temp—C	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sink Temp—C	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sink Temp—C	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Sheath Temp—C	Sheath Temp Rise—C	Expansion in Mm	Curve
20	9.5	2.5	19.3	7.3	3.0	11.5	21.5	9.0	3.0	24.3	11.5	4.5	11.2	26	12.5	4.5	11.8	19.8	8.5	2.5	10.3		3.0	A
		3.5			3.5				3.5	27.0	12.2	5.0	17	29.5	13.5	5.0	17	25.5	10.5	3.0			5.5	E
		3.0			3.0				3.0	26.7	10.2	4.0	17.5	29.5	11.3	5.0	17.5	25.5	8.1	2.5			3.0	F
		4.5			4.5				4.5	30.4	12.3	6.5	18	34.5	17	6.5	18	29.0	12.5	4.5			5.5	G
		9.5			11.5				8.5	40.5	21.5	14.0	18.5	44.8	24.3	13.0	18.5	35.0	16.5	8.5			8.5	H
30.5	8.0	3.0			3.0				2.5	32.5	9.6	4.5	25	36.5	10.6	4.5	25	33.7	7.5	2.5			3.0	I
										30.5	9.5		24	33.7	9.2		24	30.5	6.0					J
		5.0			6.0				5.0	38.5	13.5	6.0	23.5	38.1	15.4	6.0	23.5	33.7	11.0	4.5			5.0	K
		9.0			12.0				9.0	42.5	21.5	15.0	23.8	48.0	24.8	13.0	23.8	41.7	18.5	10.0			9.0	L
		3.0			3.0				4.0	32.3	11.6	6.0	24	34.7	12.5	5.5	24	30.5	8.3	3.0			3.5	M
		5.0			7.0				5.0	36.7	15.7	9.0	24	40.0	17.2	7.5	24	34.2	11.4	5.0			5.5	N
		10.0			12.0				9.0	44.2	22.7	16.0	24	49.7	26.1	14.0	24	41.5	18.3	10.0			9.0	O
28.8	7.8	3.5	28.5	8.0	4.5	21.5	29.2	8.2	3.5	32.5	12.5	5.5	21.5	36.8	14.8	5.5	21.5	31.5	9.5	3.5	31	10	3.5	B
41.0	20	12.0	40.5	20.5	10.5	19.5	41.2	21.2	9.0	53.2	34.2	23.0	20.3	60.7	39.7	17.5	20.3	44.0	24.0	13.0	44	23	10.0	C
38.5	18	10.0	38.0	19	8.0	16.8	41.5	22.0	8.5	52.0	33	25.0	19	61.5	41	16.0	19	42	23.0	11.0	42	22	8.0	D

to be very informative in the study of the expansion phenomena.

Test Results

Figure 6 has been prepared as a general picture of the increase and decrease of the linear dimensions of the six cable sections as recorded by the equipment at each end of each section. This information is presented by plotting the recorded positions at the time of maximum longitudinal expansion and maximum contraction for each end of each cable section during each test cycle. These maximum and minimum points are joined together by straight lines except for the two long-duration load cycles and for those cases where the loading was discontinued for appreciable periods. The expansion and contraction curves for these special tests have been plotted on the basis of four points taken from the record during each 24-hour period.

The scale used for longitudinal expansion in Figure 6 indicates cable motion in the manhole. No movement of cable into the duct beyond the starting point was recorded in the six sections where recorders operated.

The gaps in the curves shown in Figure 6 are the result of mechanical difficulties in the operation of the recorders. The data so lost are not of serious consequence.

Table I shows the maximum sheath temperatures measured during each test for the six sections referred to previously. It should be noted that the sheath temperatures given in the tabulation were taken at different loadings, at different ambient temperatures as shown by the sink temperature measurements and also at different load factors. The tabulation gives the expansion of the cable that appeared in the manholes at each end of each section as a result of the measured sheath temperature rise also shown in the tabulation. All of the values for expansion were obtained by scaling the curves of Figure 6.

The variation in the sheath temperature increases at the 12 test points as shown graphically in Figure 7 at four different times and at three different heating levels.

Figure 8 is a graphic report of the total expansion during each test for each of the six sections on which recorders were installed. The data for Figure 8 were obtained by adding together the recorded expansion of the two ends of each of the test sections to obtain the total expansion for each section for each test. The expansion in each case is the increase in length apparent in the manhole for each section and for an individual load cycle, without regard for expansion, permanent set, or other effects which accumulate as a result of such factors as changes in earth temperature and motion of the sections as a whole, which produce long-time changes and irregularities.

The bellows provides the force to insure good thermal contact between the thermocouple and the cable sheath at a point six or seven feet inside the duct

Figure 2. Sheath-temperature-thermocouple probe

Analysis of Tests

The first thing of interest found in analyzing the test results is that the measured temperature rise at the test points is remarkably free from radical variation with time. This is brought out particularly well in the two curves at the bottom of Figure 7 which are plotted from data taken during tests made four months apart.

Another interesting observation from Figure 7 is that the maximum variation in measured temperature rise for the whole group of test points in any test approaches two to one. This is not surprising, but it is important since it could indicate that the variation of temperature over the individual section lengths is considerable and that measurements of temperature taken at the ends of the section may not be a true indication of average section temperature.

However, the comparison of the temperature measurements at the ends of the individual sections for each test shows a range of temperature variation considerably less than that for the whole test run. Furthermore, the relationship between the individual end temperatures is maintained with change in load factor and load level as shown by a comparison of the shape of the upper curves with that of the lower curves in Figure 7.

The plotted temperature rise, Figure 7, has many of the characteristics of the

elevation profile, Figure 1, in that the maximum temperature rise of each section is at the end of maximum elevation. This characteristic, in all probability, is due to the tendency of the higher ends of the duct sections to have the minimum moisture in and around the duct bank.

Turning next to Figure 9, one sees that the shape of the curves for total measured section expansion and that of the curves for the average temperature rise have a very close similarity. It is interesting, however, that Figure 9 shows several marked deviations from this similarity in the two groups of curves. At the heating level existing on the 260-ampere four-hour cycle, the measured section expansion in all cases was less than one millimeter per degree centigrade sheath rise, whereas at the higher heating levels found in the 325-ampere 72-hour and 300-ampere 149-hour tests the section expansion was on the average above one millimeter per degree centigrade. In addition, the two lower expansion curves in Figure 9 show that for the 260-ampere four-hour loading there was considerable variation in the expansion as measured at two different times while the temperature rise showed almost perfect repetition.

The curves in Figure 10 show that the realized elongation of the cable observable in the manholes is less than 50 per cent of the theoretical free expansion of either the lead sheath or the copper conductors.

Fortunately, these three effects, nonlinear relationship of movement with temperature rise, variation with time of year, and failure to approach theoretical elongation, are of interest chiefly in studies aimed at establishing the mechanism of expansion. A given cable installation can be operated satisfactorily with only a general knowledge of the relationship between loading and expansion. This is particularly true, since the arrangement of cable in a manhole is not carried out with scientific precision and with an expectation of permanency. Cable arrangements designed to permit certain top limits of expansion in most cases will deteriorate with time, and only prohibitively expensive maintenance schedules could maintain the design conditions.

In view of these considerations, it is concluded from the temperature-expansion relations shown by the curves of Figure 9 that one millimeter of longitudinal expansion observable in the manholes per degree centigrade sheath temperature rise is a practical design factor. The length of cable section is not an important consideration, because all sections in normal operation are reasonably close to the average length of the six sections on these tests. In addition, the realized longitudinal expansion per unit length of cable is less for a long section than for a short section, and this tends to make the length of the section a rather unimportant factor in determining the anticipated longitudinal expansion.

On the system under test, two cables were carried by the same 17-inch arms in the manholes. This arrangement will accommodate about 50 millimeters of total section expansion or about 25 millimeters at each duct mouth. The 50-millimeter expansion produces about five inches of lateral movement of the splices. If there is a difference in the loading of the two cables on the same arm, the permissible lateral motion may be reduced.

The 50-millimeter limitation for total longitudinal expansion is acceptable only where the cables are properly arranged in the manholes and where the radii of curvature at the duct mouths and at the arms are appropriate. The life of the cable sheath under the flexing produced by the proposed expansion limit is not known accurately, but our interpretation of the tests reported to the AIEE last year by E. W. Osterreich is that at least 20 years of operation can be expected before sheath trouble due to expansion and contraction becomes serious. Occasional operation at higher temperatures and greater expansions should not effect the life of the sheath but may cause incidental difficulties.

The degree to which the results of these tests will apply to other installations is not known, but it is probable that the reaction of installations involving other sizes and types of cables and ducts will vary considerably from the findings given here. It is apparent, however, from these tests that the longitudinal expansion of the cable as now installed is a more serious limitation than the thermal limitations of the insulation for load cycles such as those experienced in supplying residential load.

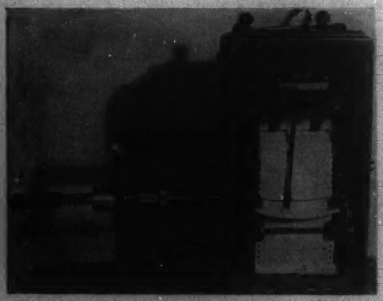

Figure 3. Expansion-recorder mechanism

The flexible shaft transmits cable motion to the recorder pen

Figure 4. Superimposed pictures to show cable motion in a manhole

The dashed lines outline the positions of the expanded cables under heavy load. The solid lines outline the contracted positions of the cables under no load

Mechanism of Expansion

The tests described in this paper were made to determine the safe limits for the loading of a specific system. However, it is felt that so much improvement can be made in the methods of constructing and installing cable as a result of a more complete understanding of the mechanism of cable expansion under load that we have examined these test results for data

Figure 5. Manhole camera installation

Care in positioning camera in manhole opening permits making a graphic record of cable motion by superimposed pictures as shown in Figure 4

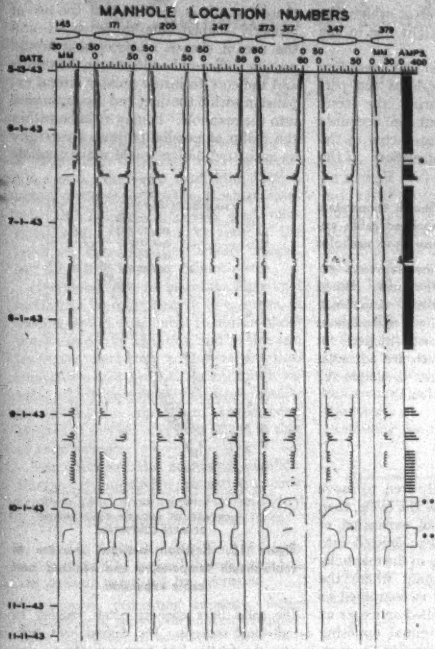

Figure 6. Continuous record of cable expansion

Motion recorded at the 12 ends of the six test sections is plotted against load cycle and date. The scale of motion at the top of the figure is in millimeters. The load cycles are of four-hour duration except those marked *, **, and ***, which are 7, 72, and 149 hours duration, respectively

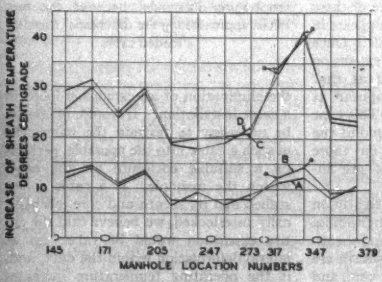

Figure 7. Temperature rise of cable sheath

The heavy, light, and dashed lines connect points plotted for temperatures measured at the ends of the same section, adjacent sections, or sections not adjacent, respectively. For test conditions see Table I

that might be helpful in this understanding. We believe the following observations warrant further consideration:

1. The amount of longitudinal expansion appearing in the manholes for a given increase in cable temperature due to losses in the conductors was different for tests made at different periods of the year.

2. The average longitudinal expansion appearing in the manholes per degree of increase in cable temperature was greater for the larger increases of cable temperature.

3. The amount of longitudinal expansion appearing in the manholes was only about one half of the theoretical free longitudinal expansion of either the copper conductors or the lead sheath (see Figure 10).

The following is a theoretical analysis of cable movement that explains these three observations. The theory is offered with the knowledge that there are insufficient test data to support it but with the hope that it may stimulate further investigation.

Consider first an idle cable in a conduit line which carries no other cables. At the time of lowest earth temperature, the cable is contracted to its minimum length and is in a straight path along the bottom of the duct. As the earth temperature and consequently the cable temperature increases, the cable expands longitudinally. The initial increase in the length of the cable is taken up principally by lateral displacement or "snaking" of the cable within the duct, since the resistance to this "snaking" is less than the resistance to longitudinal motion. Some longitudinal motion is present, and some of the increase in length appears in the manholes, in spite of the freedom of the cable to reposition itself within the duct.

The longitudinal expansion probably is due to the greater thermal expansion of the lead sheath than of the copper conductors. This undoubtedly produces a longitudinal mechanical force in the sheath, part of which is transmitted to the conductors through the insulation, so that it acts to increase the length of the entire assembly. This increase in length of the entire assembly is readily taken up as lateral displacement of the cable within the duct. However, some of the stress in the sheath must be transmitted along the sheath and is effective only as a force to increase the length of the cable into the manholes. The ability of the sheath to produce such movement is limited by the elastic deformation of the sheath and the maximum compressive force which the sheath can transmit longitudinally without permanent deformation.

At the time of maximum earth temperature, which may represent a rise of as much as 25 degrees centigrade above minimum temperature, the cable is expanded sufficiently so that the resistance to added lateral deflection or "snaking" within the duct is considerably increased and the over-all tendency for expansion is into the manholes.

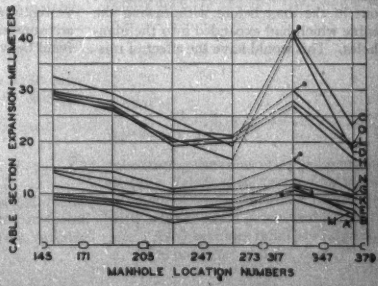

Figure 8. Cable expansion appearing in manholes

The solid and dashed lines connect points plotted for adjacent sections and for sections which are not adjacent, respectively. For test conditions see Table I

Next, assume that the cable under consideration is carrying load. The action of the forces produced by the temperature changes caused by the electrical losses must be analyzed in relation to the effects of ambient temperature which were discussed in previous paragraphs. For example, if a moderate load is placed on the cable at the time of lowest earth temperature, the longitudinal expansion starts with the cable flat in the duct. Under this condition, a large part of the increase in length is readily absorbed by lateral movement within the duct, and, for a given temperature rise, the expansion appearing in the manholes will be a minimum. However, if the same loading is placed on the cable at the time of maximum earth temperature, the increase in cable temperature is the same as before, but the amount of expansion of the cable into the manhole is from 20 to 50 per cent greater. The reason for this is, of course, is that most of the lateral freedom of the cable within the duct was absorbed by the expansion due to earth temperature increases.

The mechanism of cable movement is complicated by other variables. For example, the temperature at which an unloaded cable will assume a straight line on the bottom of the duct undoubtedly depends on previous loadings. If the cable experiences a relatively severe load cycle so that the space available for lateral displacement within the duct is fully occupied before the top of the cycle, then it would appear reasonable that the cable on cooling would tend to straighten out in the duct before withdrawing the cable which had expanded into the manholes. This would have the effect of raising the temperature level at which the cable would be in a straight line in the duct.

The theory outlined in the preceding paragraphs not only explains the performances observed during the tests reported in this paper, but also accounts for a type of damage that occurs to the lead sheath of cables in operation. If the lead sheath is reasonably free to move with respect to the core of the cable, then the forces of longitudinal expansion of the sheath are in part transmitted into that portion of the sheath in the manhole. These forces are maximum where the movement of the sheath is restrained as at a bend or at a solid-filled splice or at the location where the equal opposing forces of an adjacent section appear. Frequently this results in the lead sheath exceeding its elastic limit at one of these points, and a wrinkle or ripple appears in the sheath all around the cable. Once this ripple develops, all further expansion of the sheath is concentrated at that ripple, and failures do not appear at other locations on the sheath. This type of failure is very commonly found at the ends of splices, particularly on those installations where the cables are installed without bends.

If the lead sheath fits rather tightly on the core of the cable, the longitudinal forces developed between core and sheath due to excess expansion of the sheath are continuously transmitted to the core, and the action of the sheath in straightening the cable is reduced or possibly eliminated.

This suggests the desirability of investigating experimentally the possible advantages of improving the mechanical bond between the core and the sheath of the cable. It is possible that the use of properly shaped core-binder tapes and the use of sheath reinforcement would provide sufficient bond between the sheath and the core to insure greater lateral expansion within the duct and less expansion into the manhole. It may even be within the realm of possibility that a carefully co-ordinated design would make possible the elimination of all expansion loops in a cable installation. If would, of course, be necessary to restrain the movement of such a cable into the manhole, perhaps by a suitable enclosure for the cable within the manhole. If a cable so installed had its sheath and core mechanically interlocked, we believe that the entire expansion would be taken up as lateral deformation within the duct, and, if the operating temperature increases became high enough to cause the sheath stress to exceed the elastic limit, the permanent deformation would be spread over the entire length of cable, and there would not be localized portions of the sheath stressed to the point of failure.

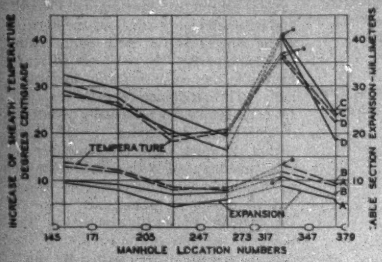

Figure 9. Sheath temperature rise and associated cable expansion appearing in manholes

The solid lines represent expansion. The heavy dashed lines represent temperature rise. The light dashed lines connect points plotted for sections which are not adjacent. For test conditions see Table I

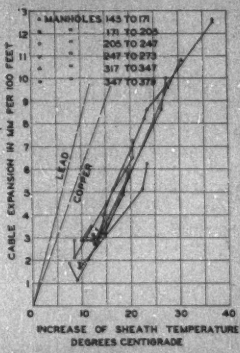

Figure 10. Relation between increase in cable-sheath temperature and realized unit cable expansion

The solid lines connect points relating to individual sections. The dashed lines indicate the friction-free temperature–expansion characteristics of lead and copper assuming a temperature differential between the two metals approximating the differential found in a loaded cable

The Summation of Load Curves

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MEMBER AIEE

A NUMBER of load curves may be added to determine some characteristics of a composite load from known values of the individual loads which comprise it. The resulting peak load, minimum load, load factor, or time of the peak are characteristics usually sought, but there may be many others.

Operators seek to maintain high load factor in a power system in given areas, in feeders, and in equipment to obtain maximum use of the facilities, and to this end loads are combined, so far as practical limitations will permit, for optimum results, which are generally measured finally by return on the plant investment. Hence the subject of rates is linked to that of load curves.

For instance, the economic justification for central-station generation as compared to local generation near individual loads, depends primarily on two facts:

1. The unit kilowatt-hour cost of energy delivered has, in general, been lessened as the amount generated has increased.

2. Relative generating capacity, feeder capacity, and substation capacity required have decreased as additional loads have been added and the demand factor has decreased due to the effects of diversity, through the serving of many loads of greatly diverse character, resulting in improved load factor or use of facilities.

The advantage for central-station generation offered by condition 2 is pertinent to the subject matter of this paper. It may be partially neutralized by adding certain types of loads in excessive amounts. The principles involved will be recognized by engineers who are striving to keep their organizations competitive and build up their revenues at the same time.

Also, in wartime, when old economic controls no longer govern, the need for intelligent load forecasting is apparent to all. It is realized now that in the haste to arm and produce, after a prolonged period of comparative business stagnation, there was much overestimation of loads, with corresponding delays because of some demands for equipment not really needed.

Forecasting under war conditions becomes difficult for load characteristics and timing have changed. Factors based upon past observations are no longer reliable. Industries that formerly operated on a single shift may now be on a 24-hour day, seven-day week basis. Wartime has changed the characteristics of lighting loads, while shortages of manpower and materials have had their effect upon commercial loads. Many utility companies have had their peak-load periods displaced as much as 12 hours under war conditions.

It is prudent to examine trends from time to time, and in so doing, one is confronted with the need to determine the components which comprise a load or conversely to determine the result of combining loads. The purpose of this paper is to consider some of the technical aspects of these problems and to present some methods which, it is hoped, will be helpful.

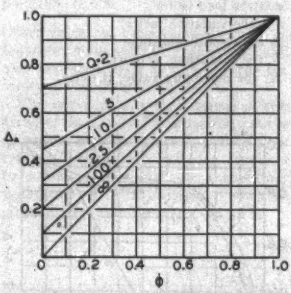

Figure 1. Δ_Q versus ϕ for various values of Q

$\alpha = 2$ and $p = 1.00$

The Addition of Loads Which Are Similar Except for Timing

An understanding of the case in which a number of loads Q, of equal load-factor ϕ, are to be combined, is helpful in determining the methods to be applied to the more general case for loads of various load factors.

In a previous paper[1] load-curve summation was mentioned briefly and the formula presented:

$$\phi_Q = \left[1 + \left(\frac{1}{\phi} - 1\right) Q^{-1/\alpha}\right]^{-1} \qquad (1)$$

in which ϕ_Q was given as the load-factor for the sum of Q equal loads of load-factor ϕ each and α was stated to be a variable of value two or greater.

A more general form of equation 1 is given by:

$$\phi_Q = \left[a + \left(\frac{1}{\phi} - a\right) Q^{-1/\alpha}\right]^{-1} \qquad (1a)$$

where a is the asymptote of the curve of $1/\phi_Q$ versus Q, instead of unity as is the asymptote given in equation 1.

In previous applications of the formula, α was taken as greater than two without introducing a value for a when adjusting for peak concentration. This procedure is not rigorous and does not give true results with any constant α for large range of values of Q and periods of peak concentration because the asymptote is variable and greater than unity when the peaks are concentrated within periods less than that for which ϕ has been calculated.[1]

A preferable approach is to find the value of the asymptote a. With α taken as a constant equal to two, a then becomes equal to s/ϕ, in which s is the coincidence factor for $Q = \infty$ as will be seen subsequently.

Further investigation has convinced the author that for utility services, the number of hours, on the average, during which peaks of a given load factor occur, decreases as the load factor decreases in accordance with probability laws which can be expressed analytically.

Let us examine the meaning of ϕ itself. Suppose a constant load lasts for a period of one hour and no longer. On this one-hour basis the load factor is 1.00; on an eight-hour basis it is 0.125; and on a 24-hour basis only 0.0417; all for the same load. So load factor must always be associated with the time for which it is measured. Also, a time restriction in the occurrence of the peaks alters Δ_Q by changing α or ϕ as given in equation 2, which, for $\alpha = 2$, applies to a random peak-time distribution during the time for which ϕ is considered. If peaks of one-hour duration should all occur during the same hour, they would be added arithmetically. This is one extreme condition. The other extreme condition would occur when the peaks are evenly distributed throughout the time considered.

Since the coincidence factor Δ_Q is the ratio of the peak for Q loads to Q times the peak for one load (the inverse of the diversity factor), we can write, taking the peak for one load as unity:

$$\Delta_Q = \frac{Q\phi}{\phi_Q} \div Q = \frac{\phi}{\phi_Q}$$

so that

$$\Delta_Q = a\phi + (1 - a\phi) Q^{-1/\alpha} \qquad (2)$$

substituting the value of ϕ_Q given in equation 1a. Values of Δ_Q versus ϕ for various numbers of loads are shown on Figure 1 with α taken equal to two and a equal to one. As Q becomes infinitely large $\Delta_Q \doteq \phi$. Also note that as $\phi \doteq 0$, $\Delta_Q \doteq Q^{-1/2}$.

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R. F. HAMILTON was with the War Production Board, Washington, D. C., at the time this paper was prepared; he is now with the Foreign Economic Administration, Washington.

Refer to Figure 2. Assume five equal momentary peak loads A, B, C, D, and E, to be concentrated and evenly distributed within a time p. The momentary peak, at the time of the peak C, of the sum of these five loads will be the sum of the five ordinates F, G, C, H, and I, spaced equally in time on the curve FCI. J, K, L, M, and N, are relative instantaneous peak values of the sum of the five loads at the times corresponding to peaks A, B, C, D, and E. Note that L is the highest of these values corresponding to the time of the peak C of the curve which is symmetrical within the time p.

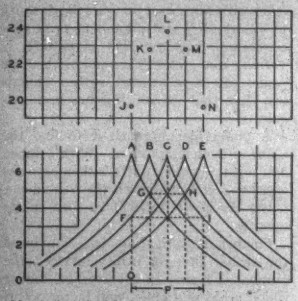

Figure 2. Five equal peak loads occurring within a time p

Now as the number of loads is increased above five, the momentary peak L of their sum will approach as a limit the integral of the curve FCI over the interval of time p. For uniform distribution with reference to time one can therefore write for equal loads:

$$M_Q \doteq Q \cdot p^{-1} \int^{p} \left(\frac{m}{M}\right) a \left(\frac{t}{T}\right) \doteq Qz \qquad (3)$$

for $Q \doteq \infty$, measuring time from the point O of Figure 2.

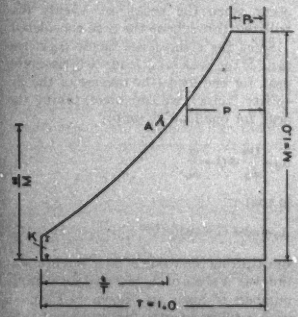

Figure 3. Reversed time-duration curve M, T, ϕ, k, and p_0 given

This equation simply states that the peak value for $Q \doteq \infty$ loads approaches Q times the average value for one symmetrical load during the interval p. This average value we have called z. For non-uniform distribution during the time p, the peak M_Q, following the most probable random distribution, will exceed Qz by an amount equal to $(1-z)Q^{1/2}$. This follows from equation 1 using $\alpha=2$ and replacing ϕ with z, or

$$M_Q = Qz + (1-z)Q^{+1/2} \qquad (4)$$

$$\Delta_Q = z + (1-z)Q^{-1/2} \qquad (5)$$

Also from equation 2 it is apparent that $a = z/\phi$ if α is to be two and equation 5 holds true.

Suppose we now set up a hypothetical load synthetically, taking into consideration minimum value, maximum value, duration of the peak, and load factor, using the methods heretofore described[1], in accordance with Figure 3:

ϕ is the load factor.
k is the variation factor.
p_0 is the peak duration.
T, the total time, is unity.
M, the maximum value, is unity.

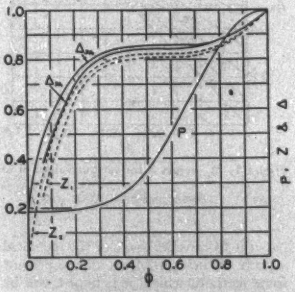

Figure 4. p, z, and Δ_∞ versus ϕ using equations 8 and 9 for z_1 and z_2

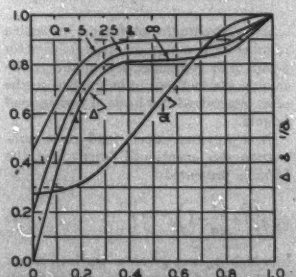

Figure 5. Curves of $1/a$ versus ϕ and Δ_Q versus ϕ for various values of Q

The curve A can be expressed as:

$$m/M = k + (1-k)(1-p_0)^{-n} \cdot \left(\frac{t}{T}\right)^n$$

where

$$n = \frac{(1-\phi)}{(\phi-k)-p_0(1-k)} \qquad (6)$$

This will represent a load-duration curve with abscissas reversed in sign.

Let p be a period of time which includes the period of the peak p_0, and $(p - p_0)$ in addition. By integrating this load-duration curve over the time p and dividing the result by p, one obtains z, the average value, and hence the load factor for that portion of the load included within the time p.

$$z = k + p^{-1}[(\phi-k) - [(\phi-k) - p_0(1-k)] \times \left[\frac{1-p}{1-p_0}\right]^v \} \qquad (7)$$

where

$$v = \frac{(1-k)(1-p_0)}{(\phi-k)-p_0(1-k)}$$

For a one-hour peak in a 24-hour cycle, $p_0 = 1/24$; also in utility curves it has been

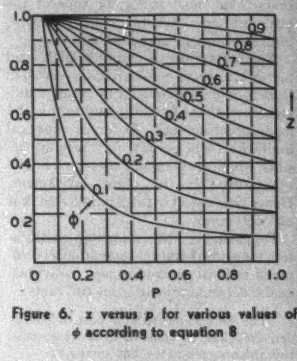

Figure 6. z versus p for various values of ϕ according to equation 8

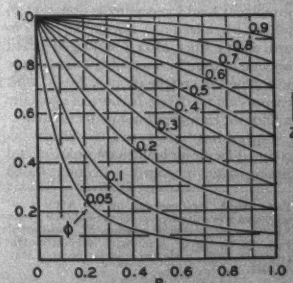

Figure 7. z versus p for various values of ϕ according to equation 9

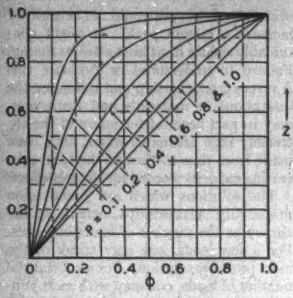

Figure 8. z versus ϕ for various values of p according to equation 8

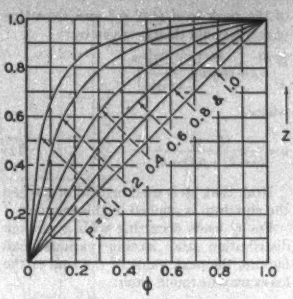

Figure 9. z versus ϕ for various values of p according to equation 9

found that one can use $k = 0.4\phi$ usually. Under these conditions:

$$z=\frac{1}{10}\left[4\phi+p^{-1}\left\{6\phi-\frac{1}{12}\,[74\phi-5]\times\left[\frac{24}{23}(1-p)\right]^{\frac{23(1-3\phi)}{74\phi-5}}\right\}\right] \quad (8)$$

For momentary peaks or for weekly and monthly load-factors for which p_0 becomes very small and where k approaches zero in value, one can put p_0 and k equal to 0 in equation 6 and then:

$$z=\frac{\phi}{p}\{1-[1-p]^{1/\phi}\} \quad (9)$$

The purpose of equations 7, 8, and 9 will be obvious. If the peaks of a number of loads Q, of equal load factor ϕ, are restricted to a time p, which is less than the time for which ϕ is calculated, then we shall use z instead of ϕ. If our cycle is one of 24 hours, then $24p$ will be the number of hours in which the peaks are concentrated.

Probability Elements as Applied to Consumers' Habits

Consider the not unusual custom of measuring all consumers' maximum demands on a unit-time basis. If these demands in kilowatts are also compared on a unit basis regardless of magnitude then, relatively, a consumer's load factor is a direct measure of his energy consumption throughout the day, and it seems logical to presume that the more energy he consumes the more likely is the time of his peak-load to vary. Stated in another form, when a substantial number of customers with about the same load factor have been segregated, it is found that the time in which the peaks occur can be correlated with the load factor. Such a correlation may be expressed:

$$p=b+ce^{-h^2(\phi)^2} \quad (10)$$

to conform to Gauss' normal probability curve.

A study of Constantine Bary's results covering large and small light and power, commercial and industrial consumers in Philadelphia, Pa., would indicate values for b, c, h^2 and $(f\phi)^2$ in equation 10 as follows[2] (see figure 4):

$$p=0.187+0.813e^{-4[(1-\phi)^2+(1-\phi)^{2.2}]} \quad (10a)$$

Other values of these quantities will be found for other special types of load and may be expected, it is believed, for the same types in other locations.

The curve of $\phi/z=1/a$ versus ϕ also assumes the shape of a probability curve as can be seen in Figure 5, and may be expressed empirically without reference to p and z. However, for momentary peak loads and with p known, a would be given by, (p_0 and $k = 0$):

$$a=\frac{1}{p}\{1-(1-p)^{1/\phi}\} \quad (11)$$

from equation 9 and likewise other values from equations 7 and 8 for the conditions therein given for p_0 and k. The quantity a is the value of the asymptote of equation 1a as previously discussed. Figure 5 also shows the variation of Δ_0 with Q, for the values of $1/a$ on the curve.

The Effect of Peak Time Concentration on the Coincidence Factor

Refer to Figure 4. The curve marked p represents values of p as calculated from equation 10a and $24p$ is the equivalent hours per day in which the total number of peak loads may be considered as concentrated. (See note following example 5 in the Appendix.)

The curve marked z_1 represents values of z calculated from equation 8 using the corresponding values for p just found.

The curve marked z_2 represents values of z calculated from equation 9 using the corresponding values of p. For z_1, p_0 is 1/24 (one-hour peak) and $k=0.4\phi$ and for z_2, p_0 is 0 (instantaneous peak) and $k=0$, as explained previously.

Note that z_1 and z_2 apply to an infinite number of loads. By concentrating the time of the peaks in accordance with curve p, we have shifted the straight diagonal line of Figure 1, $\Delta_0=\phi$, for an infinite number of cases, to one of the peculiarly shaped curves $\Delta_0=z$ of Figure 4. See also Figures 8 and 9.

Now by applying equation 5 for the summation of 30 equal loads, we obtain the two curves of Figure 4 shown for Δ_{30}

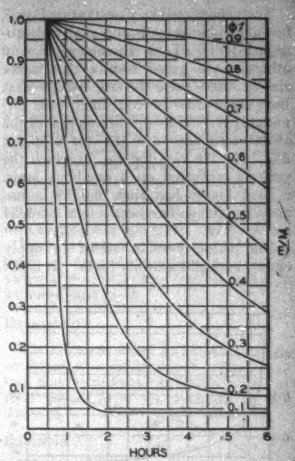

Figure 10. m/M versus hours of peak displacement for various values of ϕ using equation 12

$k = 0.4\,\phi$ and $p_0 = 1/24$

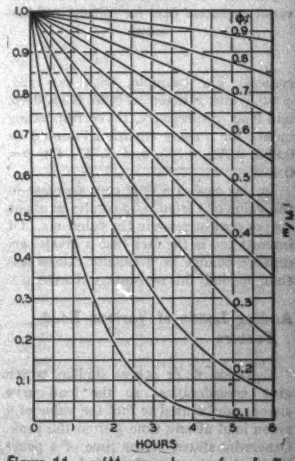

Figure 11. m/M versus hours of peak displacement for various values of ϕ using equation 12

$k = 0$ and $p_0 = 0$

Tests conducted by Constantine Bary[2], for 30 combined loads and analyzed subsequently by H. E. Eisenmenger[3], and others, have given results that agree closely with these curves, except that Bary's curve for 30 combined loads terminates at 0 for $\phi \doteq 0$, whereas that of the author terminates at 0.1825 for $\phi \doteq 0$, for Δ_{30}. In the case for ϕ_{30}, in which the peak is measured on a one-hour basis, a load factor less than 0.0675 is impossible, for p_0 has been taken at 1/24 and $k = 0.4\phi$.

The value $k = 0.4\phi$ seems to apply closely enough for utility loads. It is not

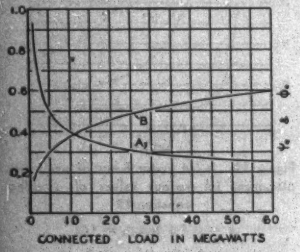

Figure 12. Demand factor and load factor versus connected load for military establishments

critical. For example, with $p_0 = 1/24$, $\phi = 0.5$, and k taken as 0.2ϕ, 0.3ϕ, 0.4ϕ, and 0.5ϕ, respectively, the corresponding values for z using equation 7 would be 0.803, 0.792, 0.775, and 0.757, for $p = 0.4$.

In this case, a 60 per cent decrease in the value of k from 0.5ϕ results in about six per cent increase in the value of z. Of interest too is the fact that a given percentage change in p usually causes less than one-half this percentage change in z.

Adding Loads of Various Load Factors

Equation 6, or others similar, which give consideration to the load-curve shape, can be used to find the value of a given load at any time p from the peak. Otherwise stated, if the time of a peak-load is known, the effect of this peak at any other time as added to any other peak or peaks can be estimated closely. This method is specifically applicable for a substantial number of peaks when their hour-to-hour characteristics are not readily obtainable, or where these vary and average values will suffice. It is not offered for a few curves as a substitute for the actual load curves if these are available. The curve for m/M, in equation 6, and others similar, is for a load duration curve with abscissas reversed. When used for direct-time readings of m/M, zero time may be taken at the midpoint of the peak load ($1/2\ p_0$) and the value of m/M would then be given by:

$$\frac{m}{M} = k + (1-k)\left[\frac{1-2p}{1-p_0}\right]^n$$

where

$$n = \frac{(1-\phi)}{(\phi-k)-p_0(1-k)} \qquad (12)$$

Note that $2p$ is used instead of p when the equation is applied in this manner.

For Q loads occurring with a random distribution and having various load factors, the peak value of the sum of the loads may be found from:

$$M_Q = \Sigma(M\phi) + \left(\frac{1}{Q}\Sigma[M^2(1-\phi)^2]\right)^{1/2} \qquad (13)$$

$$M_Q = \Sigma(Mz) + \left(\frac{1}{Q}\Sigma[M^2(1-z)^2]\right)^{1/2} \qquad (14)$$

depending upon whether the peaks are distributed throughout the cycle of ϕ or concentrated during p so that z becomes applicable as heretofore discussed. These follow from equations 2 and 4.

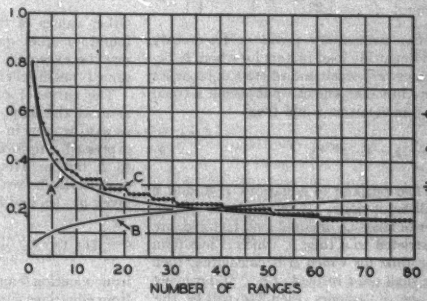

Figure 13. Demand factor and load factor versus number of electric ranges

$p = 0.5$

The corresponding coincidence factors Δ_Q may be obtained from equations 13 or 14 by dividing M_Q by ΣM.

The Effect of Load Changes on Coincidence Factors and System Peaks

Coincidence factors have been employed to estimate the effect of an additional load on an existing peak load. It will be seen that this method can be applied only when the existing peak occurs during a time in which the additional load is apt to occur. If the time of a principal peak load has shifted, the relations which determine the relative contributions to this peak load are certainly altered. A single industrial customer, in the change from 8-hour to 16- or 24-hour operation, has correspondingly increased his load factor and, therefore, the hours during which his maximum demand (which may have remained constant) is likely to occur. The effect of a substantial number of such load changes would not necessarily increase a system peak. It might conceivably reduce it, at least alter its timing. Failure to understand or evaluate this Δ versus ϕ relationship and to foresee the limitations in materials and manpower, may in part account for many of the extremely high estimates which have been made from time to time of the total generating capacity needed for the war effort.

The solutions which are based upon probability relationships increase in accuracy as the number of loads increases. For a few loads, one may speak of the most probable solution. For a substantial number of loads, one may with more confidence speak of the actual solution for some of these intangible problems.

Demand Factors for Composite Loads

Since, for unit loads of all load factors, the load factor of the summation of a substantial number of such loads increases as the number of loads increases, it is apparent that the demand factor will decrease for given types of loads as the connected load increases. If the demand factor for Q loads is ψ_Q and the connected load is β_Q

$$\psi_Q = \frac{M_Q}{\beta_Q} = \frac{\Delta_Q \Sigma M}{\Sigma \beta} = \frac{\phi_1 Q M_1}{\phi_Q Q \beta_1}$$

$$= \frac{1}{\phi_Q}[\phi_1\psi_1] = \Delta_Q \psi_1 \qquad (15)$$

Thus, for loads of a given load-factor type ϕ_1, ψ_Q is proportional to $1/\phi_Q$, since $[\phi_1\psi_1]$ is a constant value for that type of load. M_1/β_1 represents the kilowatt demand per kilowatt of connected load for the unit load, and, therefore, $[\phi_1\psi_1]$ is the average load per kilowatt of connected load.

It has been determined that by dividing a given type of connected load into Q hypothetical unit blocks of 10, 100, or 1,000 kw each, useful empirical relations may be established for the demand-factors.

For example, for military establish-

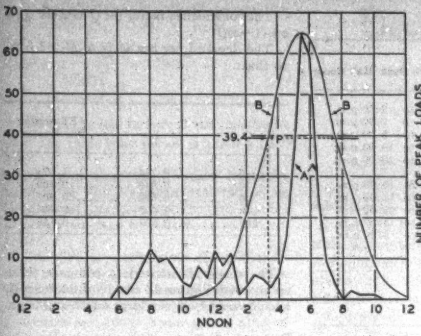

Figure 14. Frequency curve for individual electric-range peak loads

ments of certain kinds ranging in magnitude of connected load from 5,000 to 50,000 kw, the demands have been found to fall within or near the values given by the above relations with $p=1.0$, $\phi_1=0.159$, and $\psi_1=0.935$ for 1,000-kw unit blocks of connected load as given on curve A of Figure 12. Curve B of the same figure is for the corresponding load factors.[4]

Another example, for domestic electric ranges, is illustrated by curve A of figure 13 which represents demand factors versus number of ranges for $p=0.5$, $\phi_1=0.05$, $z=0.10$ (equation 9), and $\psi_1=0.8$. Curve B is for the corresponding load factors and curve C gives values of demand factors as given in the National Electric Code.[5]

Conclusion

The more one delves into this subject of load-curve analysis, the more apparent does it become that here is to be found an opportunity for research, particularly by utility companies, which should be profitable. It is hoped that in this brief paper, a few load-curve relations have been presented in a manner that will point to the possibilities for further investigations.

To explain more fully practical applications of some of the formulas presented, additional figures and a few examples are included in the Appendix.

Appendix

Symbols Employed in the Paper

ϕ—Load factor
Δ—Coincidence-factor
p—Peak-concentration factor (or peak-shift factor)
p_0—Peak-duration factor
k—Load-variation factor
z—Coincidence-factor for an infinite number of similar loads
Q—The number of loads
Δ_Q—Coincidence-factor for Q loads
M—Maximum value of a load
M_Q—Maximum value for the sum of Q loads
ψ—Demand factor
β—Connected load
α—An empirical number, value two or more
Σ—Sign of summation for terms following
T—Time of load cycle
t/T—Fraction of load cycle (in time)
m/M—Fraction of peak load (in power)

Explanation of Additional Figures

Figure 6 shows the z versus p relationship for various values of ϕ as calculated from equation 8, in which $k=0.4\phi$ and $p_0=1/24$.

Figure 7 shows the z versus p relationship for various values of ϕ, as calculated from equation 9, in which $k=0$ and $p_0=0$.

Figure 8 corresponds to Figure 6 except that the relationship of z versus ϕ of equation 8 is given for various values of p.

Figure 9 corresponds to Figure 7 except that the relationship of z versus ϕ of equation 9 is given for various values of p.

Figure 10 gives values of m/M versus hours of peak displacement for various values of ϕ as calculated from equation 12 with $k=0.4\phi$ and $p_0=1/24$.

Figure 11 gives values of m/M versus hours of peak displacement for various values of ϕ as calculated from equation 12 with $k=0$ and $p_0=0$.

Example 1

The ten loads shown in Table I are to be combined on a single circuit. What peak load may be expected at 6:00 p.m. and at 9:00 p.m.? Refer to equation 12 and Table II.

Example 2

What peak load may be expected on a power feeder which is to carry the loads shown in Table III? Peaks are on a 15-minute basis. In this case $p_0=1/96$. Take $k=0.4\phi$ and apply equations 7 and 14. See Table IV.

$$M_Q=3{,}436+\left(\frac{1{,}020{,}444}{10}\right)^{1/3}=3{,}755 \text{ kw}$$

$$\Delta_Q=\frac{3{,}755}{5{,}600}=0.67$$

(Note: average $z=0.633$)

Table I

Number	Kw Maximum	Kw Minimum	Time of Peak, P.M.	Peak Duration Minutes	Kilowatt-Hours Per Day
1	10,000	500	6:00	30	48,000
2	2,000	100	5:30	60	12,000
3	2,500	250	8:00	15	24,000
4	5,000	500	4:15	5	60,000
5	1,000	80	7:20	30	8,400
6	4,500	900	9:00	60	64,800
7	1,800	630	4:30	15	34,560
8	900	15	3:30	15	4,320
9	500	60	7:30	60	3,600
10	1,000	150	4:45	20	3,600
	29,200				

Table II

Number	ϕ	k	p_0	p, 6 P.M.	p, 9 P.M.	M, 6 P.M.	M, 9 P.M
1	0.20	0.05	0.0208	0.0000	0.1250	10,000	2,342
2	0.25	0.05	0.0417	0.0208	0.1458	2,000	611
3	0.40	0.1	0.0104	0.0833	0.0417	1,830	2,169
4	0.50	0.1	0.0035	0.0729	0.1979	4,204	2,859
5	0.35	0.08	0.0208	0.0556	0.0694	796	739
6	0.60	0.2	0.0417	0.1250	0.0000	3,636	4,500
7	0.80	0.35	0.0104	0.0625	0.1875	1,737	1,580
8	0.20	0.02	0.0104	0.1042	0.2292	327	59
9	0.30	0.12	0.0417	0.0625	0.0625	344	344
10	0.15	0.04	0.0139	0.0521	0.1771	410	63
						25,283 kw	15,276 kw

Peak load at 6:00 p.m. 25,283 kw
Peak load at 9:00 p.m. 15,276 kw

Table III

Number	Kilowatt-Hours Per Day	Kw Peak	Hours in Which Peak May Occur
1	1,200	100	9:00 a.m. to 9:00 p.m.
2	1,800	300	9:00 a.m. to 7:00 p.m.
3	8,640	600	8:00 a.m. to 8:00 p.m.
4	1,440	200	10:00 a.m. to 10:00 p.m.
5	6,000	1,000	4:00 p.m. to 10:00 p.m.
6	9,600	2,000	5:00 p.m. to 10:00 p.m.
7	13,440	700	12:00 m. to 12:00 m.
8	1,080	50	12:00 m. to 12:00 m.
9	1,440	400	5:00 p.m. to 11:00 p.m.
10	600	250	4:00 p.m. to 8:00 p.m.
	42,240	5,600	

Table IV

Number	ϕ	p	z	Mz	$M^2(1-z)^2$
1	0.5	0.500	0.699	70	906
2	0.4	0.417	0.665	200	12,800
3	0.6	0.500	0.781	469	17,266
4	0.3	0.500	0.408	94	11,321
5	0.25	0.250	0.592	592	166,464
6	0.2	0.208	0.563	1,126	763,876
7	0.8	1.000	0.800	560	19,600
8	0.9	1.000	0.900	45	25
9	0.15	0.208	0.458	183	4,700
10	0.10	0.167	0.387	97	23,486
		Average z=0.633		3,436	1,020,444

Example 3

Tests made on a few electric ranges of a given type indicate an average maximum demand of 3.5 kw for one range, and a monthly consumption of 125 kilowatt-hours. At 80 per cent transmission efficiency, what will be the increase in a utility company's 7:30 p.m. peak load if the maximum probable use of the ranges occurs at 5:30 p.m. and 10,000 of these ranges are to be placed on the system?

SOLUTION

The load factor for one range ϕ=125 kilowatt hour per month−range/720 hours per month×3.5 kilowatts per range = 0.0496.

The peak-time-concentration factor p= 0.188 (from equation 10).

The coincidence factor for an infinite number of ranges (or the load factor per range for the time-concentration factor p) = 0.26 (from equation 9).

The coincidence factor for 10,000 ranges Q is Δ_Q=0.2674 (from equation 5).

The demand for 10,000 ranges Q is $M_Q=\Delta_Q Q M_1/0.8$ for 80 per cent efficiency. So that

M_Q=(0.2674)(10,000)(3.5)/0.8=11,699 kw, 5:30 p.m. range peak.

Now the load-factor for Q ranges, $\phi_Q=\frac{\phi}{\Delta_Q}$=0.1865.

The peak-time-shift factor, p_s=2 hours per day/24 hours per day=1/12.

The fraction of the range peak at 7:30 p.m. is m/M=0.447 (equation 12).

So the range load contribution at 7:30 p.m. is $m/M\times M_Q$=5,229 kw.

Example 4

Neglecting transmission losses, what peak demands per heater may be expected for groups of 5, 10, 20, 170, and 500 single-unit domestic-type water heaters of 1,500 watts rating, considering that the maximum use will occur between 7:30 a.m. and 8:30 p.m. and the average monthly consumption per heater is 300 kilowatt-hours?

SOLUTION

The load-factor for one heater ϕ=300 kilowatt-hours per month per unit/720 hours per month×1.5 kilowatts per unit = 0.278.

The peak-time-concentration factor p= 13 hours per day/24 hours per day=0.542.

The coincidence-factor for an infinite number of heaters (or the load-factor per heater for the time-factor p) is

$$z=\frac{\phi}{p}\left\{1-(1-p)^{1/\phi}\right\}=0.482$$

The coincidence-factor for Q heaters $\Delta_Q=z+(1-z)Q^{-1/2}$.

The demand per heater is $\Delta_Q M_1$=1.5 Δ_Q so that:

Q	Δ_Q	Kilowatts Per Heater
5	0.714	1.071
10	0.646	0.969
20	0.598	0.897
170	0.522	0.783
500	0.505	0.758

The reader is invited to compare these results with Figures 14 and 16 of reference 6, which were based on a large number of tests.

Example 5

A proposed military post for 40,000 officers and men is expected to have the wintertime loads shown in Table V.

For purposes of determining the capacity of the service feeders and transformers, find the maximum load, the average load over a three-hour period, and the rms value over three hours.

SOLUTION

See Table VI. The quantity p is from equation 10, and z is from equation 9.

$$M_Q=3{,}477+\left(\frac{464{,}679}{3}\right)^{1/2}=3{,}871 \text{ kw maximum demand}$$

M_Q is from equation 14.

$$\phi_Q=\frac{33{,}200}{24\times 3{,}871}=0.357$$

For a displacement of 1½ hours from the peak load:

m/M=0.717=k_2 (using equation 12 with k=0.4ϕ and p_0=0)

z_2 = 0.852 (using equation 7 with k=0.4ϕ and p_0=0)

z_2 is the load factor over the three-hour period. So that average value over three hours=3,871×0.852=3,297 kw.

Table V

Type	Connected Kilowatts	Daily Use, Kilowatt-Hours	Hours Use of Maximum Demand
1. All lighting	4,100	16,000	8
2. Heating and cooking	4,000	12,000	6
3. Power and miscellaneous	1,500	5,200	10
	9,600	33,200	

Table VI

	ϕ	p	z	M	Mz	$M^2(1-z)^2$
1	0.333	0.226	0.791	2,000	1,582	174,724
2	0.250	0.202	0.735	2,000	1,470	280,900
3	0.417	0.273	0.817	520	425	9,055
					3,477	464,679

To find the rms value of load use equation 5 of reference 1. Thus

$$\theta = s^2 + \frac{(s_2 - k_2)^2}{\left(\frac{1-k_2}{1-s_2}\right)^2 - 1} = 0.7945$$

where θ is the loss factor, so that rms value over the three-hour period is $\sqrt{\theta}M = 3{,}450$ kw.

The peak time-concentration factor p, as used in the foregoing example, is an "equivalent time" in which the total number of peak loads may be considered as concentrated.

Actually, in certain types of loads, there may be a frequency distribution of these peak loads which can be represented graphically by a frequency polygon of peak concentration about some given time at which the density of the peak concentration will be a maximum value or mode of the frequency distribution. While not conclusive, it would seem from a limited number of cases that p may be taken as that time (or fraction of the total time of a cycle) which, if squared and multiplied by the total number of peak loads, will give the sum of the second moments about the axis of the mode of the frequency polygon. Abscissas in this polygon would represent times of the class intervals of the peak loads and ordinates would be the numbers of peak loads falling within the various frequency rectangles.

Mathematically, $p = [Q^{-1}\Sigma(p_c Q_c)]^{1/2}$ for the frequency polygon and, if the number of loads becomes large, $p = 1/\sqrt{2}\,h$ where h is the modulus of the probability curve relating p_c and Q_c, thus

$$Q_c = Q_m e^{-(hp_c)^2}$$

and $p = \sigma$, the standard deviation.

Refer to Figure 14 which shows on curve A the peak-load-time distribution for 50 nine-kilowatt electric ranges found in a recent test in Philadelphia over a period of one week, as furnished by Constantine Bary.

Curve B is the probability curve whose standard deviation is equal to the $[Q^{-1}\Sigma(p_c Q_c)]^{1/2}$ of curve A, namely 4.44 hours or, as a fraction of one day, $p = 4.44/24 = 0.185$. Compare this with the value of p in example 3 which was taken from equation 10.

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Electrically Operated Gyroscopic Instruments

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NONMEMBER AIEE

THE topic "Electrically Operated Gyroscopic Instruments" covers a very wide and interesting field in which our work includes, for the most part, instruments and systems closely associated with aircraft, navigation, and control.

Gyroscopic instruments for aircraft originally were air-operated because of the availability of pneumatic pressure from the simple Venturi tube. As the use of electricity aboard airplanes became prevalent, the advantages of electrical operation were applied to the gyroscopic instruments.

The electrically driven gyroscope may be divided into the three commonly used types:

1. The vertical gyroscope.
2. The directional gyroscope.
3. The rate gyroscope.

Since the vertical gyroscope is used for stabilizing the directional reference, the directional gyroscope may be disregarded in this discussion.

Gyroscopes may be classified under the two phenomena associated with rotating bodies:

1. Stability or the fixity of the spin axis in space.
2. Precession or the reaction of the spinning body to a torque about an axis other than the axis of rotation.

Gyroscopes are characterized by the requirements of the maximum moment of inertia about the rotational axis and maximum rotational velocity. The equation $T = I\Omega\omega$ defines the relationship between applied torque, moment of inertia, precessional velocity, and spin velocity in either the vertical or the rate gyroscope. In both types the rotor is designed to provide the largest possible moment of inertia and is constructed, so that it is exterior to the stator. For most purposes the gyroscope is an induction motor designed to operate at 400 cycles from single- or three-phase supply, 110 or 26 volts. Rotor speeds for the large gyro are 10,000 rpm and for the smaller units 20,000 rpm. Power consumption is between four and six watts.

Vertical Gyroscopes

In the vertical gyroscope (see Figure 1) the equation $T = I\Omega\omega$ defines the rigidity of the gyroscope. T is an index of the amount of torque which the gyro can resist in the form of friction and disturbing forces. Its importance in the field of aircraft control has been occasioned by the necessity for a fixed reference, regardless of changes in the aircraft's attitude. High velocities, accelerations, pitch, bank, poor visibility, and great altitudes have made it imperative that fixed axes be established to provide reference for control, navigation, bombing, fire control, and so forth. For the purpose of establishing attitude, a stable vertical reference is required. The gyroscope possesses the necessary stability, but it must also be responsive to the earth's gravitational field, so that it may become vertical. A free gyroscope established in the vertical soon would depart from that position because of such factors as precession caused by friction, departure from vertical caused by the earth's rotation, and departure caused by the motion of the craft on the earth's surface. To insure that the gyroscope remains vertical, a device called an erection mechanism (see Figure 2) causes the gyroscope at all times to precess into the vertical axis. The response of the gyroscope and its erection mechanism to the gravitational field cannot be separated from its response to any other acceleration. The problem of seeking the vertical, therefore, is one of separating gravitational acceleration from random accelerations and from those introduced by maneuvers of the craft. Since it is impossible to separate them instantaneously, the combination of the gyroscope and its erection mechanism is so designed that the response of the system to accelerations is very slow. Under these conditions the random accelerations will cancel out over a period of time, while those caused by maneuvers are responded to so gradually, that departure from the vertical, even in extreme cases, is small. Since the gravitational acceleration is constant and continuous, the gyro is at all times corrected to the vertical during normal, straight, and level flight.

Basic Gyro Vertical

We have three gyroscopic elements characterized by different sizes of gyrorotors. The gyro vertical (see Figure 3)

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consists of an induction motor in which the rotor comprises the gyroscopic mass and is external to the stator to secure maximum moment of inertia. The axis of rotation of the motor is normally vertical. Attached to the housing is the erection mechanism. The rotor, stator, housing, and erection mechanism comprise the gyromotor. This gyromotor assembly is supported on ball-bearing pivots in a gimbal ring, which in turn is supported on ball-bearing pivots in the main housing. The axes of the gimbal support are perpendicular to each other and to the rotor axis. It follows that the two gimbal axes are normally in a horizontal plane. The gyromotor is in a universal joint, and the gyro axis is free in two horizontal axes about its rotational axis. The basic gyro vertical therefore can be described as a gyroscope with three degrees of freedom provided with an erection mechanism.

The erection mechanism (see Figure 2) consists essentially of a steel ball rolling in a circular track. A disk with a slot is mounted above the track allowing the ball to run freely within the limit set for it by the slot. The ball on this track acts as a level and reacts to the inclination of the track, which is perpendicular to the rotor spin axis. A circular magnet attached to the gyrorotor shaft turns inside a drag cup attached to cause the disk to turn. The magnetic coupling is designed so that the disk turns at approximately 30 rpm.

When the gyro axis is vertical the ball travels with uniform velocity, and there are no unbalanced forces. Displacing the gyroscope inclines the track, causing a nonuniform ball velocity due to acceleration. An escapement mechanism, built into the disk, is provided to restrain the speed of the erection system when the gyroscope is in the vertical position and still provide sufficient torque for correct operation of the mechanism when the gyroscope is displaced from the vertical.

The mechanism is so designed and balanced that the rotating mass of the ball, due to its variable velocity, exerts a precessing torque upon the gyroscopic system at an angle of 90 degrees from the inclined angle of the gyroscope to the vertical. The chief consideration is that the variable velocity of the rolling ball creates an erecting torque on the gyroscope which persists until the track is horizontal, at which time the gyroscope is vertical, the ball speed is uniform, and no further unbalanced forces exist. In all three of the gyro verticals power is supplied through the gimbal suspension by means of hairsprings or insulated pivots. The selection of rotor and gimbal bearings is an important problem, since these instruments must function through a temperature range of from −54 degrees centigrade to +70 degrees centigrade; the available torque exerted on the gyroscope is minute and any imperfection in the gimbal bearings will result in failure to attain required accuracy to vertical.

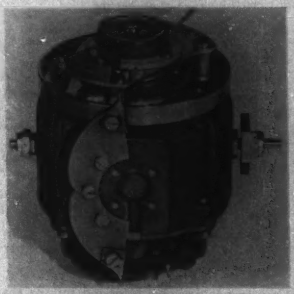

Figure 2. Vertical gyroscope showing erection mechanism

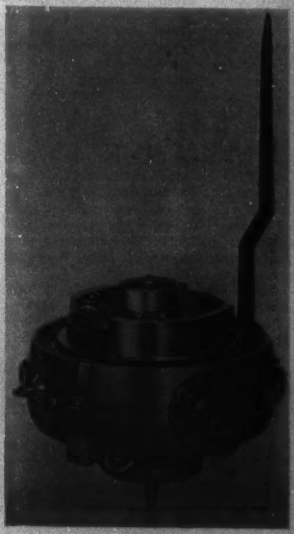

Figure 3. Basic vertical gyroscope (applied for gyro roll indicator)

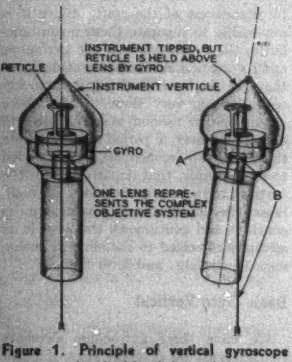

Figure 1. Principle of vertical gyroscope (applied for driftmeter)

A. Schematic gyroscope shown hollow to allow light to pass through, although it is solid in the instrument, and the light is reflected aside by a prism

B. Although the lens is tilted, it still directs the vertical ray to the center of the reticle

Precessional Gyroscope

The characteristics of the precessional gyroscope (see Figure 4) are given again by the equation $T = I\Omega\omega$ in which T is the precessional torque, I is the rotor moment of inertia, Ω is the angular velocity to be measured, and ω is the angular velocity of spin. It is evident from the equation that an angular velocity imposed on a spinning mass will result in a torque which is proportional to that angular velocity. The precessional or rate gyromotor is similar in construction with the gyro vertical in that it consists of an induction motor comprising an internal stator, an external rotor of maximum moment of inertia, a motor housing, and a set of pivots in gimbal bearings attached to the external housing. The basic-rate gyro can be described as a restrained gyroscope with two degrees of freedom. Angular velocity about the reference axis causes a precessional torque about the restrained axis. The torque acts against appropriate springs, causing a displacement proportional to the imposed angular velocity. In a specific case, the rate of turn indicator for aircraft, the rotor axis is in a horizontal plane athwarthship, the gimbal axis is in a horizontal plane along the fore and aft axis. The rate of turn to be measured is about a vertical axis, and the precessional torque is exerted about the fore and aft axis against restraining centralizing springs.

Production Problems

The imposition of severe restrictions in space and weight on instruments designed for aircraft requires the use of components of small size and extreme precision. For example, decreasing the length of an axis by 50 per cent automatically calls for a 50 per cent reduction in allowable tolerance to maintain the same angular accuracy.

The problems attending the production, inspection, and assembly of small parts of high precision have forced the adoption of methods of manufacture, such as coin-

ing, centrifugal casting, and forging in extreme accuracy and small size. Accuracy requirements have resulted in adoption of production techniques capable of maintaining ±0.0001-inch tolerances. Assembly and calibration of these instruments necessitates a technique where the microscope and the vacuum-tube amplifier are essential parts of production and inspection equipment. Dynamic balancing of the small high-speed rotors required the development of a production balancer of novel design in which the rotor is operated, and the location of unbalance in either of two correction planes is marked at the location of metal to be removed by means of an electric arc. An indication of required depth to be drilled is secured and the rotor balanced by drilling out the prescribed amount at the marked spot by means of an integral drilling fixture on the machine. In this manner rotors of several ounces in weight are balanced to a residual unbalance not greater than 0.00001 ounce-inch.

The assembly of these instruments must be done in air-conditioned rooms with extreme emphasis on constant temperature, freedom from moisture, dust, and contamination. Investigation of sources of contamination indicate necessity for eliminating even the handling of parts with fingers and the development of technique, whereby vital parts are never touched with the hands. The use of cleaning methods and cleaning materials has been investigated fully to the extent that special equipment and specially prepared washing solutions have been attained and held to rigid specifications. The problem of testing, cleaning, and lubricating ball bearings was, in itself, a project of considerable scope requiring the development of highly specialized equipment and production techniques.

Gyro Horizon Indicator

This instrument may be used to fulfill two purposes. It serves to transmit signals in pitch and bank for automatic pilot control, or it may serve as a visual reference to the human pilot indicating the attitude of the plane. The unique feature of this instrument is its small size. Heretofore, the artificial horizon has been of larger size due to difficulties of manufacture and required accuracy. With the development of the small gyro vertical we have been able to produce an instrument of standard interchangeable size with other aircraft panel instruments (that is, $3^1/_8$ inches in diameter), which fulfills the requirements of accuracy for both indication and autopilot control. The gyroscope consists of an induction-type motor driven by three-phase 26-volt current supply. The motor draws five watts. The rotor of this instrument has a speed of 20,000 rpm. To secure the highest-possible moment of inertia, a centrifugally cast silver-alloy rotor with an integral squirrel cage is used. The gyromotor is mounted in a fork-type gimbal ring which, in turn, is mounted on a main pedestal in the rear of the instrument housing. Transmission of pitch and bank signals is accomplished by small signal generators on the pitch and bank axis. Conductors supplying power to the gyromotor and bringing out electrical signals are provided in the combination of contact pins and hairsprings. Some conception of the problems involved in the development of this instrument may be glimpsed from the fact that within the space of $3^1/_8$ inches in diameter by 6 inches in length is provided a gyro vertical of accuracy within 20 minutes of absolute vertical with freedom of ±100 degrees in bank, 80 degrees in dive, and 70 degrees in climb, transmitting signals of attitude in pitch and bank.

Figure 4. Principle of precessional gyroscope

Driftmeter

The gyro-stabilized driftmeter (see Figure 5) is an optical instrument designed to provide the navigator or bombardier with a stable reference with which to compute drift, ground speed, and bearings of terrestrial landmarks from the airplane independently of the pitch and roll of the aircraft.

The driftmeter consists of a vertical telescope through which the ground may be viewed and upon which is superimposed the image of a gyroscopically stabilized reticle. The system is so designed that, with pitch and roll of the aircraft, there is no relative motion between the image of the ground and the reticle, and so an observer can see what is apparently a stationary image against the reticle. The motion of the ground due to flight can be referred to reference lines on the reticle and accurate readings of drift obtained. The telescope is provided with scales in azimuth and in elevation, so that for certain purposes accurate bearings may be obtained. The gyroscopic element of the driftmeter is the large gyro vertical, consisting of the rotor of 5,000 grams centimeters squared moment of inertia, a rotor speed of 10,000 rpm, power supply of 400 cycles, 110 volts, single phase, and power consumption of approximately seven watts. This gyroscope does not contain any signaling devices, and current is brought into the gyromotor through the gimbal rings by means of insulated pins in hollow pivots concentric with gimbal bearings. The gyro is calibrated to an accuracy of better than ten minutes from true vertical.

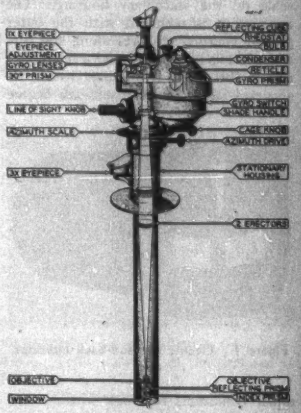

Figure 5. Driftmeter

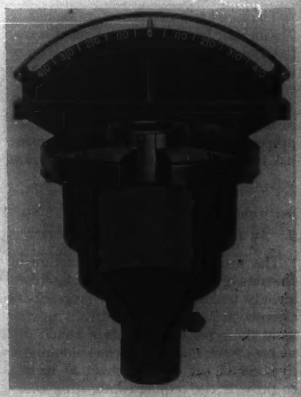

Figure 6. Gyro roll indicator

Gyro Roll Indicator

The roll indicator (see Figure 6) is an example of the application of an aircraft

type of gyro vertical to marine use. For the purpose of fire control on board a medium-size vessel it was necessary to provide an accurate indication of the ship's roll with respect to true vertical. For this purpose the gyro used in the driftmeter was adopted. A special housing is provided and a pointer attached to the gimbal ring, the pointer being read against a scale on the stationary housing. The instrument is mounted with the outer gimbal bearing supports along the fore and aft axis of the ship and a reading of roll of the vessel is obtained within an accuracy of better than one-half degree

Figure 7. Electric turn-and-bank indicator

under conditions of rough weather and maneuvers.

Electric Turn-and-Bank Indicator

The turn and bank indicator (see Figure 7) is an instrument which combines the two functions that indicate the rate of turn of an aircraft and the resultant acceleration which is, in general, referred to as bank. The combination of these two indications results in correctly executed turns at proper banking angles. This instrument has been developed in three basic types:

1. Utilizing an air-driven gyroscope.
2. A d-c-driven gyroscope.
3. An a-c-driven gyroscope.

The principles and basic structure of the rate gyroscope have been described already under the heading "Precessional Gyroscope." In the d-c-driven instrument the gyroscope consists of a small d-c motor on the shaft of which is mounted a flywheel of sufficient moment of inertia to provide the required indicating characteristics against the centralizing springs. The motor current is supplied to the 24-volt shunt motor through contact pin connections to the case.

The a-c-rate gyroscope consists of an induction motor of which the rotor is the gyro mass. The rotor is exterior to the stator and rotates at a speed of 20,000 rpm. Power supply is 26 volts, three phase, 400 cycles at approximately four watts. The instrument serves as an indicator and also as a transmitter for aircraft control. At one end of the pivot axis is located a signal generator which provides electrical signals as a function of the angular velocity of the aircraft. Power supply and signal leads are in the form of hairsprings from gyroscope to case.

Gyro Flux Gate* Compass System

The Gyro Flux Gate compass system is a remote indicating earth-inductor gyro-stabilized compass. The system is composed of a gyro-stabilized Flux Gate transmitter, a master indicator, an amplifier, and repeater indicators. Its advantages are based on the fact that the magnetically sensitive compass element or Flux Gate is located in a position free from the magnetic and electrical disturbances usually found in the pilot's and navigator's stations, and that the Flux Gate is gyro stabilized and is thus maintained in a horizontal position at all times. As a result of this stabilization, turning and acceleration errors, for all practical purposes, are eliminated.

The Gyro Flux Gate transmitter (see Figure 8), with which we are concerned primarily, is a gyro vertical of the larger size, similar in electrical characteristics to the driftmeter type. Operating power is supplied at 110 volts, 400 cycles, 6 watts to the gyro induction motor. The motor stator is, again, inside the rotor and consists of a two-phase four-pole winding, one of the phases being in series with capacitors mounted on the gyromotor to provide the necessary quadrature current. In the bottom of the gyromotor housing is mounted a magnetic detector sensitive to the direction of the magnetic field in its plane. As a result, steady and accurate compass readings are obtained independently of pitch, bank, and maneuvers of the aircraft.

Automatic Pilot

This system comprises a combination of units, the purpose of which is the control of an airplane in attitude, direction, and through selected maneuvers. In the application of electrically driven gyroscopes to the automatic pilot, three of the instruments previously described are used. These are the artificial horizon, the Gyro Flux Gate transmitter, and the turn and bank indicator.

The artificial horizon transmits electrical signals of the attitude of the airplane with respect to the vertical to suitable devices for the purpose of control. These devices consist of amplifiers and servomotors which actuate the control surfaces of the airplane and maintain attitude.

The gyro-stabilized Flux Gate transmitter is also a two-purpose instrument in that it serves to transmit the magnetic heading of the aircraft for the purpose of indication and to provide a directional reference through amplifier and servo-system to the rudder-control surface.

The turn-and-bank indicator, likewise a dual-purpose instrument, serves to indicate the rate of turn-and-bank angle of the aircraft and to transmit the rate signals to combine with the directional signal of the Gyro Flux Gate system in such a manner that precise directional control is obtained. The rate signal is used further to control the desired rate

Figure 8. Gyro Flux Gate compass transmitter

of turn and to execute precision turns of correct banking angle.

To summarize, the electric gyroscope in aircraft instrumentation is rapidly supplanting air-driven types, owing to the following factors:

1. Freedom from air-supply requirements at high altitudes.
2. Sealing and elimination of air supply, thus preventing contamination and insuring greater reliability.
3. Greater versatility, especially where electrical signaling devices are required.
4. Compactness, greater reliability under extreme temperatures due to speed regulation and torque characteristics.

Since the development of electrically driven gyroscopes for instrumentation is a relatively new art, many interesting and very important applications still are to be anticipated.

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The Copper-Oxide Rectifier in Electrochemical Work

I. R. SMITH
ASSOCIATE AIEE

MUCH has been written about the copper-oxide rectifier during the 23 years of its existence, yet the subject is far from exhausted. It still remains one of the most interesting developments of recent years. A brief résumé of its history may be of interest.

The scene opens in 1921 when L. O. Grondahl discovered that a large area of copper coated with cuprous oxide would act as a rectifier. Five years later the rectifier known as the Rectox was introduced commercially for use in trickle charging "A" batteries in home radio sets. This became a tremendous business overnight but disappeared with the same disconcerting speed two years later with the advent of a-c tubes. Application of the rectifier to industrial uses started in 1927 and after a period necessary for trial and acceptance by users began to develop rapidly, reaching its peak during the past three years in many diversified war activities.

Though this may be familiar material to many, it will be worthwhile to run through those characteristics which particularly apply to the use of the rectifier in electrochemical work. A copper-oxide rectifying element is an integral unit consisting of a disk or plate of high-purity copper, coated on one or both sides with red (cuprous) oxide. The combination is shown schematically in Figure 1. It is an asymmetric resistor, that is, it passes current better in one direction than in the other. Current flows readily from oxide to copper, but with difficulty from copper to oxide.

This is best illustrated by a typical volt-ampere curve, which is simply a curve showing how much current flows in either direction for any given voltage, Figure 2. To illustrate, if one applies three volts in the low resistance direction, a current of nine amperes will flow through a $1^1/_2$-inch-diameter disk. If the voltage is then reversed, the current flow will be perhaps one milliampere, a ratio of 9,000 to 1.

From the shape of the curve, one can see that resistance in either direction is not a constant. This is better shown by Figure 3, on which is shown the variation in resistance with voltage for both directions of polarity.

These characteristics do not remain fixed but vary with temperature and also with time and operation. The forward resistance will tend to increase over a long period of time, the amount depending upon the temperature, while the back resistance will decrease somewhat during operation. These effects are known as aging. The effect of temperature is to cause both forward and back resistance to decrease as temperature increases, and vice versa.

The construction of copper-oxide rectifier units is by now familiar to many users. There are two general types, one involving a high degree of pressure on the rectifying element, the other requiring practically no pressure.

The pressure-type construction is applied to disk rectifiers used for relatively small capacities. A variety of such units is shown in Figure 4. The rectifying disks are strung on insulated bolts, with thin lead washers placed against the oxide surface. Radiating fins and metal spacers may be added, and the whole structure then pulled together under a pressure of over 1,000 pounds per square inch. This gives a solid, rugged type of unit that has stood the test of all kinds of service for many years.

The other type of construction is employed on plate-type rectifiers. A cross-sectional view is shown in Figure 5. The rectifier plate, to begin with, has oxide on both sides, whereas the disk is coated only on one side. The plate oxide is then reduced to copper on its outer surface, and the copper is plated over with nickel. Contact then must be made to both nickel surfaces. This is done with large spring washers, insulated from the plate copper, and pulled down and riveted together with a metal bushing. This construction thus parallels the two sides of the plate and furnishes the negative connection. The copper or positive connection is obtained by removing the oxide around a second hole through the plate. Figure 6 shows three sizes of plates with their connectors.

Plate rectifiers are used with natural convection cooling, but more often with forced draft. The plates are assembled on insulated studs, about one-half inch apart. This is ideal for forced cooling, as the cooling air comes in direct contact with nearly all of the active surface.

From one point of view, the method of determining a rectifier rating is of no interest to a user since he buys the rating he wants and expects that the manufacturer will have determined the rating properly. However, a user who does know more about the unit than just what is stamped on the name plate, can certainly operate with greater intelligence and with less likelihood of getting into trouble.

The method used is very simple to understand but the application of it is a matter involving considerable time and work. That, however, is the designer's problem.

Basically, the rectifier is a thermally rated device, like a transformer or a motor. Due to its internal resistance,

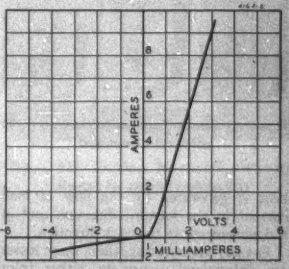

Figure 2. Typical volt-ampere curve for single copper-oxide disk

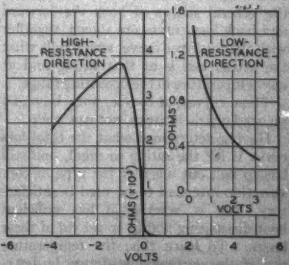

Figure 3. Typical resistance-voltage curve for single copper-oxide disk

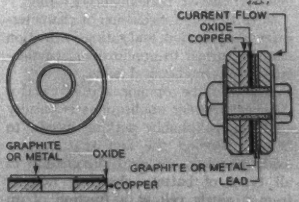

Figure 1. Diagrammatic cross section of single copper-oxide disk

Paper 44-163, recommended by the AIEE committee on electrochemistry and electrometallurgy for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944. Manuscript submitted April 14, 1944; made available for printing May 16, 1944.

I. R. SMITH is section engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Figure 4. Group of Rectox disk-type units

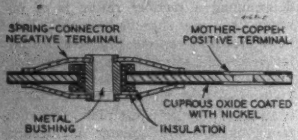

Figure 5. Diagrammatic cross section of Rectox plate

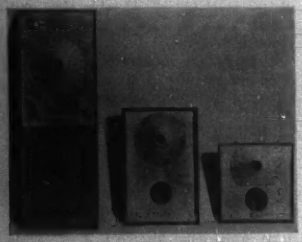

Figure 6. Standard copper-oxide plates with connectors assembled

heat is generated by the flow of load current in the forward direction and of leakage current in the back direction.

For any given rating, then, these losses are determined separately, either from volt-ampere curves or from actual tests, covering a range of operating temperatures. The separate losses are then combined into a total loss curve. In Figure 7 the general shapes of both the forward and back loss curves are shown, together with the total loss curve, which tells what the actual loss is at that rating and at any temperature in the operating range.

These curves, of course, must be based on aged characteristics, not new ones.

Having determined what the total loss curve is for the rating in mind, one still has to find out whether the type of construction intended to be used is satisfactory, that is, whether it has sufficient heat-dissipating ability to get rid of these losses. To learn this, the temperature rise of the particular structure is determined as a function of the watts to be dissipated in the structure. This gives a heat-dissipating curve which can be matched with the total loss curve to show what is the right combination.

How this works is shown in Figure 8. The heat-dissipating curve for the unit is curve *D*, drawn with the ambient temperature as a starting point. Also shown are three total loss curves. These are for the same total output. Curve *A*, however, is the total loss in a rectifier operating at high voltage and low current, curve *B* for one operating at high current and low voltage, and curve *C* for median values of voltage and current. Curve *C* corresponds to actual commercial ratings. Inspection of this figure shows that the combination of *A* and *D* is unsatisfactory. The two curves do not intersect and the rectifier would consequently burn up at this rating. Curve *B* intersects *D* at a broad angle and is obviously very safe since if temperature rises for any reason, losses will actually decrease. Curve *C* is also quite safe, crossing *D* at a reasonably wide angle.

Since curves *A*, *B*, and *C* are for the same output, their relative positions indicate the relative efficiencies. Curve *B*, it can be seen, has obtained exceptional safety at the expense of efficiency. Curve *C* gives good efficiency and satisfactory safety with a margin in case of occasional operation at higher than rated ambient temperature. Curve *C* also gives approximately the same losses and efficiency over the entire range of temperature, which is desirable. It follows also that the operating temperature, which is at the intersection of the loss curves and the heat dissipation curve *D*, is much lower for curve *C* than any other rating.

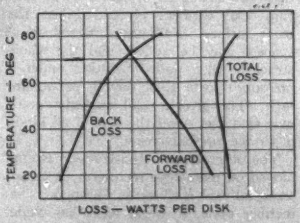

Figure 7. Relation of internal losses to unit temperature

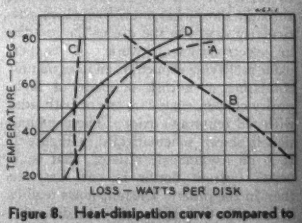

Figure 8. Heat-dissipation curve compared to total-loss curves for different disk ratings but same unit output

With this brief discussion of characteristics, construction, and ratings, attention may be turned to applications, particularly in electrochemical fields.

Of course, the commonest of all electrochemical rectifier applications is battery charging. Probably nothing needs to be said beyond the fact that copper-oxide rectifiers are used successfully in all types of battery charging, ranging from a single cell at a fraction of an ampere to a 2,500-ampere 12-volt charger. Of interest is the 12-cell one-ampere oil-immersed charger shown in Figure 9. The use of oil immersion for protection against corrosive atmospheres is likely to expand rapidly. Figure 10 is included to show a fully automatic charger for industrial-truck batteries. This charger will handle up to 18 cells of lead-acid battery, and up to 450 ampere-hours capacity. The charger automatically gives the battery its proper rate, regardless of the state of charge. At the correct point, the rate is reduced to the desired finishing rate, and at the end of the finish charge, the rectifier shuts down and disconnects the battery. A companion model is available for nickel-alkaline batteries.

The next application is not so widely known except in the oil industry. That is the cathodic protection of pipe lines. It was found about 15 years ago by R. J. Kuhn and others that pipe-line leaks could be prevented if the pipe could be maintained cathodic, that is, negative to the surrounding soil. This was reasonable, since leaks occur due to loss of metal where the pipe is anodic, the soil being an electrolyte. To make the pipe cathodic, that is, to force it to be negative to the earth at every point, a source of direct current was connected between the pipe and ground plates in the surrounding earth. The system is shown simply in Figure 11. When such an installation is properly designed, the result is complete stoppage of leaks. The requirements are for relatively small-capacity units, delivering up to say ten volts at up to 100 amperes, the units being mounted on poles or platforms along the pipe line at intervals of the order of a mile. Operation, of course, is continuous.

For this work the copper-oxide rectifier has been used since the beginning. It has good efficiency, which is important since operation is continuous and power rates are sometimes quite high. It can be mounted in a weatherproof box for outdoor service. It has no moving parts and requires no maintenance, and will operate for long periods without any need for adjustment. Figure 12 shows one of the many thousands of such units in service. Figure 13 illustrates a fan-cooled Rectox

built for this type of work for outdoor service.

A kindred application is the protection of water tanks and similar structures. Figure 14 shows a diagram of a typical installation. Electrodes placed in the water maintain a protective film of hydrogen over the inner surface of the tank, preventing corrosion and eliminating the need for painting. The units are of small capacity costing little to operate, and the installation as a whole is easy to justify economically. The requirements are similar to those for cathodic-protection rectifiers.

In the chemical and metallurgical field, electrostatic separators and Precipitrons are frequently used. These require a high-voltage source of small direct currents. Figure 15 shows a power supply for a metal separator which delivers 15,000 volts at a few milliamperes to the electrodes. The use of a copper-oxide rectifier is attractive in this field because of the elimination of tubes and tube replacements. The higher first cost of the copper-oxide unit is felt to be justified by the freedom from later maintenance and the cost of tubes.

In the field of anodizing and plating, rectifiers have reached great prominence during the war. This has resulted to quite an extent from the shortage in rotating equipment, so that many people had to use rectifiers for plating and anodizing who otherwise probably never would have tried them. Now that they have gained familiarity with rectifier operation and its advantages, it is believed rectifiers will be preferred for many plating applications.

In Figure 16 is shown a standard stock rectifier for plating work, rated six volts, 500 amperes maximum. It is fan cooled, takes less than 4 square feet of floor space, stands 38 inches high, and weighs about 600 pounds. It is designed so that one or two more units can be mounted on top, thus economizing on floor space for larger capacities. These units are connected in parallel or series, as desired, for larger outputs, and are controlled from a separately mounted step-type regulator. The regulator unit then is mounted close to the operator, while the rectifier cubicles are located where they are not subject to corrosive fumes. The units being fan cooled are exposed to large amounts of room air during their operation and cannot be used safely in a corrosive atmosphere.

The unfortunate effect of corrosive atmospheres on copper-oxide plates (in which in fact they are no different from other types of electric apparatus) led to the design of a totally enclosed rectifier which could be installed right in the plating tanks. This type of rectifier was supplied for two continuous strip-tinning lines. The rectifiers are mounted two high and are right next to the plating tanks, which are also on two levels. This resulted in a

Figure 9. Oil-immersed Rectox battery charger
Rating one ampere, 12 cells

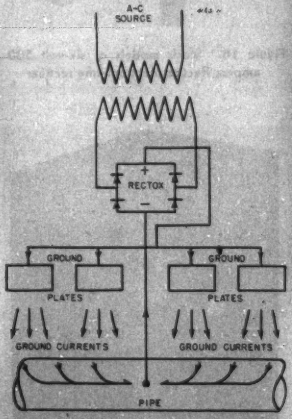

Figure 11. Diagrammatic representation of cathodic-protection system for pipe lines

Figure 13. Outdoor fan-cooled plate-type Rectox for cathodic protection

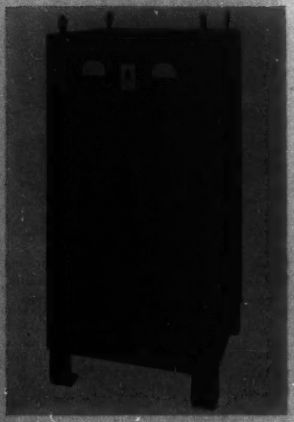

Figure 10. Automatic charger for industrial-truck batteries

Figure 12. Installation of pole-mounted Rectox for cathodic protection

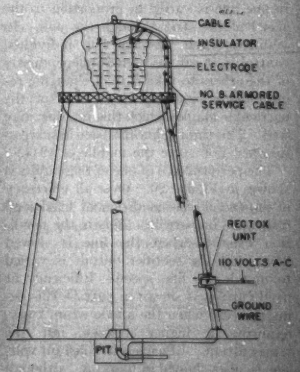

Figure 14. Diagrammatic representation of protective system for water tanks

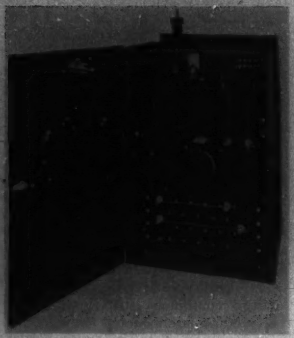

Figure 15. A 15,000-volt five-milliampere Rectox for metal separator

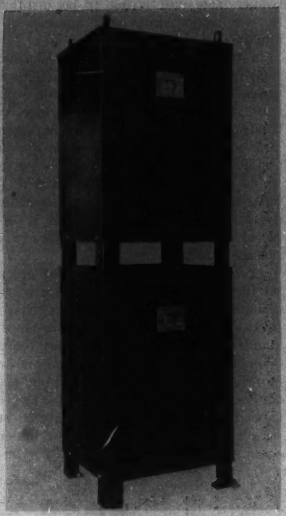

Figure 16. Stock models of six-volt 500-ampere Rectox electroplating rectifier

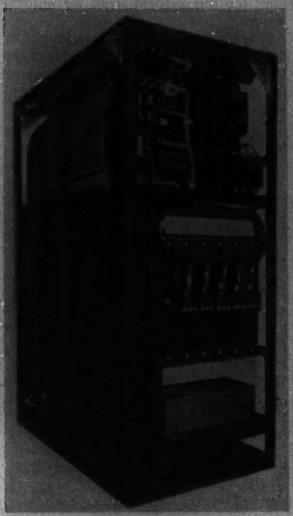

Figure 18. Totally enclosed rectifier showing arrangement of blowers, air duct, and control

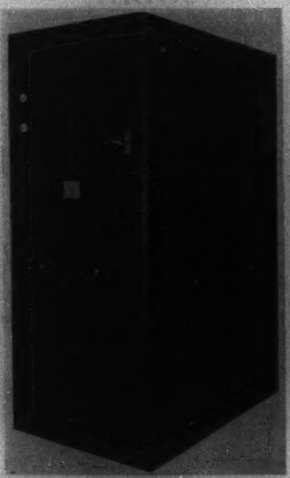

Figure 17. 12-volt 2500-ampere totally enclosed Rectox electroplating rectifier

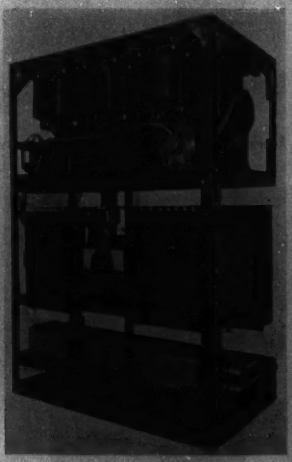

Figure 19. Totally enclosed rectifier showing heat exchanger, Rectox plate assemblies, power transformer, and saturable reactors

tremendous saving in bus copper, estimated to have been 80,000 pounds.

Figures 17 to 19 show the construction of one of these rectifier units, rated to deliver six volts, 5,000 amperes, or 12 volts 2,500 amperes direct current. Ventilating air is circulated through the unit in a closed system by a double blower. Heat is removed by a water-cooled heat exchanger. The rectifier power transformer is located between the two six-volt 2,500-ampere blocks of rectifier plates. In the top of the cubicle are three saturable reactors, used to control the output of the rectifier over a range of ten to one in both voltage and current. Contactors controlling the power to the rectifier and to the blower motor, type *AB* disconnecting breakers for the rectifier and for the control circuit, and temperature and fan-failure relays are all located at one end of the cubicle for accessibility.

An automatic control system is used by which the output of all the 24 rectifiers in one line is varied in proportion to the speed of the strip through the mill. In addition, each rectifier has individual control so it can be varied independently of the others to take care of changing requirements resulting from wear of the particular anodes which this rectifier may feed. This tinning line has been in successful operation since the middle of 1943.

The performance of one of these units is shown in Figure 20. Over-all efficiency is shown for the condition of fixed load resistance in part B. This is the condition existing when the line is slowed down and the rectifier output is varied to match the line speed. Efficiency at fixed current is shown in part D, this being the case when the anode wears away, requiring a higher voltage, but the same current. Efficienoy at constant voltage is also shown in part A, although this is not a condition which occurs in the operation of the plating line. Power factor for the fixed resistance load is shown in part B, the power factor being determined mainly by the saturable reactors in the primary circuit. Other curves show the variation in output in terms of the variation in the saturating current of the reactor, and the variation in reactor voltage and transformer secondary voltage for the range of output voltage. Saturable-reactor control has the advantage of lending itself well to automatic operation and also of giving the same smooth variation in output as is obtained by rheostatic control of a generator.

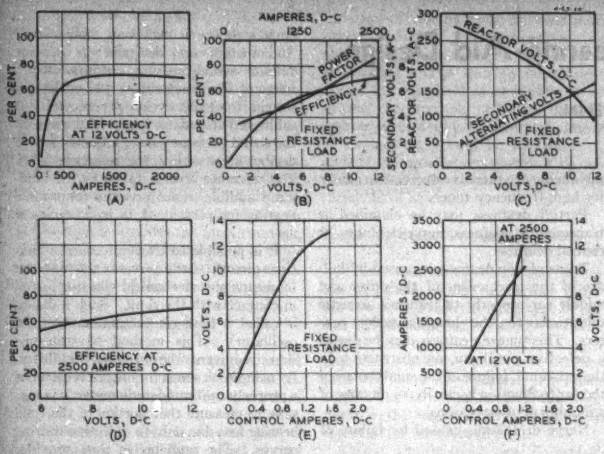

Figure 20. Performance curves of totally enclosed 12-volt 2,500-ampere rectifier

The circuits used in these applications are few in number and simple. Generally the ones involved will be found among those shown in Figure 21. It is not intended to discuss these here in any detail. Generally the single-phase and three-phase bridge circuits are used for electrochemical applications. Occasionally the full wave and the three-phase double wye may be used, their purpose being to obtain points of maximum efficiency at voltages half way between the maximum efficiency points of the bridge. Thus, if the bridge circuit gives maximum efficiency at 6, 12, 18 volts, and so on, the full-wave or the double-wye circuits will give maximum efficiency points at 3, 6, 9, 12, and so on.

In electrochemical applications, involving often continuous operation or operation over long periods, efficiency of the rectifier is of prime importance. This is true not only for full rating but for voltages below full rating. It will be realized that many six-volt plating rectifiers operate at only three or four volts. In cathodic-protection work a survey made several years ago of some 3,000 units in service showed that 75 per cent were operating at less than one-half their voltage rating, while only 2 per cent were at or near full rating. It is peculiar to this application that full output may be required when operation begins, but that after a period the power-output requirements reduce greatly due to polarization of the pipe line.

Hence the efficiency is important at partial voltages as well as at full voltage. In this respect, the copper-oxide rectifier is favored because of its low forward resistance, resulting in less reduction in

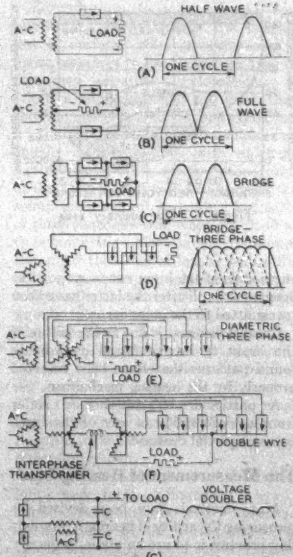

Figure 21. Circuits commonly used for metallic rectifiers

efficiency for partial voltages than is the case with some other types of rectifiers. Figure 22 shows how efficiency varies with voltage output, load being constant.

Long life is also a very desirable feature in electrochemical work. In this respect, the copper-oxide rectifier is supreme in its field, measuring its life in years rather than in hours.

Figure 23 is given to show how little actual effect aging has on performance. In November 1939 the first large electroplating Rectox was installed in which the plates had the plated-nickel contact coating. In Figure 23 the performance of this rectifier when installed is shown as curve *A*, while the performance after 4½ years of service is shown on curve *B*. Study of these two curves shows there has been no discernible effect due to forward aging. The slight reduction at light loads is due to what aging has occurred in the back direction. Full load is obtained on exactly the same transformer tap now as when installed. Voltage regulation consequently shows no apparent change over the period. Prevailing ambient temperature for this rectifier is about 25 degrees centigrade.

This installation illustrates well the advantages of a plating rectifier. Here is a power plant that has operated over a 4½-year period with the same full-load performance at all times, and with no expense to the user as yet for maintenance or repair of the rectifying units.

In Figure 24 is a typical life curve of the disk-type Rectox units used in operating d-c elevator brakes and control. This curve was taken on a large number of units in the field and shows a practical

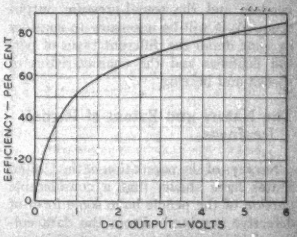

Figure 22. Variation of efficiency with load voltage at constant load for three-phase bridge Rectox

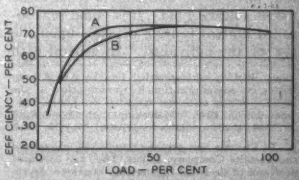

Figure 23. Efficiency curves showing effect of 4½ years of service on a six-volt 2,000-ampere plating rectifier

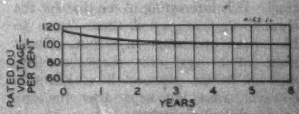

Figure 24. Field test on Rectox units supplying power for elevator control and brakes

Fundamentals of Hearing-Aid Design

W. D. PENN
ASSOCIATE AIEE

A HEARING AID is a miniature sound-amplifying system which is worn on the person in order to help overcome the handicap of impaired hearing. To be effective a hearing aid must be capable of amplifying those frequencies necessary for intelligibility of speech and reproducing them at a high-intensity level so as to make normal conversation audible to the person with impaired hearing. Modern hearing-aid amplifiers are of the vacuum-tube type, using small tubes designed specifically for them. A complete hearing aid consists of a microphone, a vacuum-tube amplifier, a receiver, and the necessary battery supply and connecting cords. Usually the microphone and amplifier unit are housed in a single case and the receiver and battery supply are connected to the amplifier by means of flexible cords. In order to determine the amount of amplification necessary, the type of frequency response needed, and the sound-pressure output required, it will be necessary to consider in some detail the different types of partial deafness and the characteristics of speech and hearing.

The Nature and Extent of Partial Deafness

Surveys of the population of the United States have shown that a considerable portion of the people have some form of defective hearing.[1] From the data collected it is possible to estimate the percentage of the population having a hearing loss greater than any particular designated value. Approximately four per cent have losses sufficient to require the use of a hearing aid. It is found that so-called normal hearing depends upon the age of the individual. In general with advancing age there is a decrease in acuity for high-frequency tones.

Partial deafness may be classified as transmission deafness, nerve deafness, or central deafness.

Transmission deafness is caused by failure of the mechanism of the outer and middle ear properly to transmit acoustic vibrations to the hearing nerve centers. This type of deafness may be due to a defective ear drum, an obstruction in the ear canal, failure of the small bones of the ear to function normally, or any one of a number of other reasons.

Nerve deafness is caused by failure of the nerves of the inner ear to respond to acoustic stimuli after the latter have been transmitted to the inner ear.

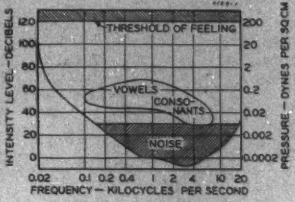

Figure 1. The auditory area

Central deafness is due to the failure of the brain to interpret and co-ordinate sound patterns that have been received properly by the hearing mechanism.

A particular individual may suffer from a combination of any of the three types of partial deafness.

The Measurement of Hearing Loss

Many methods have been devised for measuring the acuity of hearing. Present-day practice is to use an audio-frequency oscillator in conjunction with a telephone receiver which has been calibrated in terms of its acoustical sound output. Such a device is called an audiometer.[2] Audiometers are designed to provide definite sound-pressure outputs over a range of frequencies from 128 cycles per second to 8,192 cycles per second. A calibrated attenuator is provided whereby the sound pressure can be adjusted in five decibel steps above the reference level. The reference level is taken as the minimum audible sound pressure for normal hearing for persons of 18 to 23 years of age.

It is possible to transmit sound vibrations directly to the nerves of the inner ear by means of a mechanical vibrator placed in contact with the skull. Such a device is called a bone-conduction receiver (or oscillator). This method of transmission circumvents the outer and middle ear. By using such a unit for output receiver of a properly calibrated audiometer, it is possible to measure that portion of the total hearing loss due only to defective hearing nerves. The audiometer thus provides a means of measuring the minimum sound pressure required to evoke a sensation of hearing either by air conduction (telephone receiver) or by bone conduction. A curve showing the minimum audible sound pressure at different frequencies is called an audiogram. The audiometer measures the minimum sound pressure required for audibility and really is a measure of what is *not* heard rather than what is heard.

In estimating an individual's capacity for understanding speech from his audiogram, it is necessary to take into consideration the relative effects of different frequencies on the intelligibility of speech.[3]

The Auditory Area

The frequency range for normal hearing has been established as being from 20 to 20,000 cycles per second. The ear does not respond uniformly to sounds of different frequencies, so the minimum sound pressure required for audibility varies over the frequency range. The curve showing the minimum audible sound pressure is called the threshold of audibility curve. If at any frequency within the hearing range the sound pressure is increased progressively above the minimum audible pressure, an upper limit at which a sensation of pain occurs is reached. This upper limit is relatively

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stabilization of the output voltage with time. It is interesting to see that for the three-to-six-year period there seems to have been no change in output. These same units by now have an additional seven years of life. Records, however, were not kept after the six-year point was reached.

Laboratory units are still running which were started in 1926-28, so it is correct to say that there appears to be no limit to the life of a copper-oxide rectifier.

Conclusion

Electrochemical applications characteristically require high operating efficiency at all voltages up to full rating, operation free from maintenance, and long life. Some of these applications are among the oldest in which the copper-oxide rectifier has been used, and in which it has achieved great success. Familiarity with the rectifier is daily increasing, due to the much enlarged use of the past few years. It is believed that this ground will not be lost, but that the advantages of the copper-oxide rectifier will result in further expanding its use as these advantages become more generally recognized.

constant with frequency. The curve showing the maximum sound pressures is called the threshold of feeling.[4]

The area enclosed by the threshold of audibility and threshold of feeling curves, between the upper and lower limits of frequency is known as the auditory area. For a sound to be heard by an individual it must fall within the auditory area of that person. Usually there will be some particular intensity level in the auditory area of the partially deafened person which provides the most comfortable hearing. If a hearing aid is used, the intensity can be adjusted to the proper level by means of the volume control.

Characteristics of Speech

The prime purpose of a hearing aid is to amplify speech sounds so that maximum intelligibility results for the user of the aid.

The sounds of speech are composed of combinations of different tones spread throughout a range of frequencies from 100 cycles per second to 8,000 cycles per second. The vowel sounds embrace a range from approximately 100 to 2,500 cycles per second. Consonants consist mainly of high-frequency tones extending from 1,000 to 8,000 cycles per second. Each sound of speech is characterized by certain groups of frequencies and, unless these groups are present in the proper proportions, the speech will not be intelligible no matter how loud it may be.

Some frequency bands are more essential to the understanding of speech than others. The low frequencies of speech furnish the greater part of the acoustic energy. The high frequencies contribute the greater part of the intelligibility. Thus eliminating all frequencies below 500 cycles per second reduces the distinctness by only four per cent while reducing the acoustic energy by 62 per cent. On the other hand, eliminating all frequencies above 500 cycles per second reduces the distinctness or intelligibility by 93 per cent and removes only 38 per cent of the energy. There is but little loss of intelligibility if the range from 200 to 4,000 cycles per second is transmitted.[5]

Studies of the intensities of the various frequencies present in normal conversational speech show that they are distributed throughout the auditory area approximately as indicated in Figure 1.[6] The left hand ordinate of Figure 1 gives the intensity in decibels above a reference intensity of 10^{-16} watts per square centimeter. The reference pressure is thus 0.0002 dyne per square centimeter or 0.0002 bars. The right hand ordinate gives the pressure in bars. Examination of Figure 1 indicates that the principal voice frequencies vary in sound pressure from a minimum of 0.006 bar to a maximum of 0.6 bar. Expressed in decibels this would correspond to a volume range of 40 decibels. There will be some variation of volume range between individual speakers. For recognition of speech a volume range of 30 to 40 decibels is essential. If a hearing impairment causes the threshold of audibility to be so near the threshold of feeling that the auditory area does not encompass a range of 40 decibels, it will be impossible to understand speech even though it be amplified sufficiently to place it above the threshold of hearing.

Need for Selective Amplification

It has been pointed out that partial loss of hearing occurs in various forms. No two people with the same type of partial deafness will suffer exactly the same hearing loss at each frequency. In general, those suffering from nerve deafness hear low frequencies better. They hear sounds but do not understand the words because the high-frequency sounds are essential for intelligibility.

Unless the hearing loss is uniform throughout the frequency range it is necessary to utilize frequency selective amplification. Even though the hearing loss is uniform, it is advantageous in many instances to use the proper type of frequency selective amplification. If selective amplification is not used, then the frequencies which the individual has no difficulty in hearing will be amplified equally as well as those with which he has difficulty. The relative proportions of the various frequencies comprising the sound then will not be correct and some of the frequencies will become so loud as to be annoying. They might reach even the upper threshold of feeling before the other frequencies are sufficiently loud to indicate the characteristics of the speech sounds. Examination of Figure 1 shows why this occurs. If the areas representing the speech sounds are moved uniformly upward, the vowel sounds strike the feeling curve long before the consonants. Thus the vowel sounds will tend to mask the weaker consonant sounds which are essential for intelligibility if uniform amplification is used.

It appears then that for good intelligibility some form of frequency selective amplification must be used. Previous considerations of the characteristics of speech and hearing have shown that for intelligibility the high speech frequencies are necessary and that the low frequencies are not so important. From the manner in which the speech sounds are distributed in the auditory area, it is also apparent that when the hearing loss is severe it is necessary to attenuate the low frequencies in order to be able to bring the high-frequency sounds above threshold and still not have the low frequencies strike the threshold of feeling.

Attenuation of the low frequencies usually results in some increase in intelligibility even when the hearing loss is uniform. This is because in average room noise the intensities are higher for the low frequencies which thus produce a masking effect which can be lessened by reducing the intensity of these components.

From the above considerations it is reasonable to conclude that the type of selective amplification used should be such as to make possible attenuation of the low-frequency end of the spectrum. The control should be of the variable type since each case will be somewhat different.

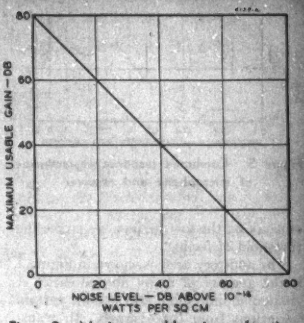

Figure 2. Maximum usable gain as a function of noise level

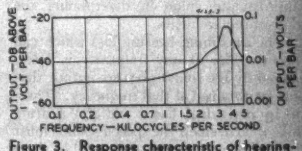

Figure 3. Response characteristic of hearing-aid microphone

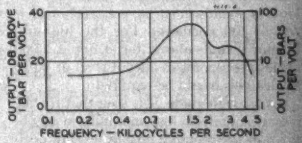

Figure 4. Response characteristic of hearing-aid receiver

Output Requirements

The maximum sound-pressure output which a hearing aid must be capable of producing can be determined from the chart of the auditory area. If uniform amplification is used, the speech level can be raised until the frequencies in the region from 500 to 1,500 cycles per second strike the upper threshold of 200 bars. The higher frequencies will then have pressures of from two to 20 bars. If the frequencies below 1,500 cycles per second are attenuated, it is possible to raise the output pressure at high frequencies with-

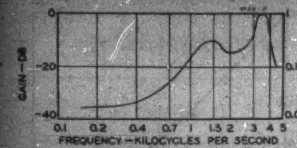

Figure 5. Combined response characteristic of microphone and receiver

out having the low frequencies strike the threshold of feeling.

The auditory area as shown in Figure 1 is the average of many normal ears. A particular individual will exhibit certain variations from the average. In transmission deafness it is probable that the threshold of feeling also is raised. The above figures nevertheless serve as an approximate guide in determining the output requirements.

The maximum hearing loss which can be overcome at any frequency is determined by the sound-pressure output that can be obtained at that frequency. Thus, if an individual has a uniform hearing loss of 60 decibels the speech sounds must be raised in intensity so that all of them are above a 60-decibel intensity level. Since the range between the loudest sound and the weakest is 40 decibels the loudest sounds must have a level of 60+40 = 100 decibels. For the high-frequency sounds above, for example, 2,000 cycles per second an output level of 60 to 80 decibels would be required.

As a rough guide, it is seen that for the case of a uniform loss and uniform amplification the required output level in decibels, L, must equal the hearing loss, HL, in decibels plus 40. That is

$$L = HL + 40 \qquad (1)$$

From equation 1 it would appear that with uniform amplification and uniform loss, the greatest hearing loss which could be overcome would be 80 decibels and in order to overcome a loss of this magnitude the hearing aid would have to be capable of supplying a pressure of 200 bars for frequencies less than 1,500 cycles per second and 20 bars for frequencies greater than 1,500 cycles per second.

If, as is often the case, the hearing loss increases with frequency then in order to bring the high-frequency components necessary for intelligibility above the impaired threshold and still not let the low frequencies reach the threshold of feeling, it is necessary to attenuate the low frequencies.

If the loss is greater for low frequencies the requirements are not so severe because this does not reduce greatly the intelligibility. Also, as mentioned previously, the type of hearing loss characterized by decreased acuity for low tones is usually due to transmission deafness and the upper threshold is raised so that uniform amplification can be employed with less possibility of striking the upper threshold of feeling. A recent tabulation of audiograms indicates that only 13 per cent of those tested had characteristics which showed a loss greater for low frequencies than for high frequencies. Increasing loss with frequency was shown by 43 per cent and 44 per cent had a uniform characteristic. Ten per cent of the total number showed a loss greater than 80 decibels.[7]

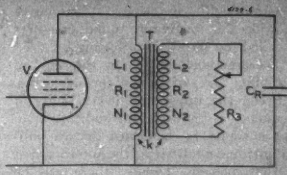

Figure 6. Circuit for controlling frequency response

Nonlinear Distortion

If the relation between output sound pressure and input sound pressure is not linear, nonlinear or amplitude distortion occurs. Vacuum-tube amplifiers can be made to operate as substantially linear devices if certain limits of operation are not exceeded. However, no amplifier has an unlimited output capacity and so as the input signal is increased progressively a point finally is reached beyond which the output is not directly proportional to the input. Since the amplitudes are largest in the output stage, most of the distortion occurs there. As a result of the nonlinear relation between input and output, new frequencies are created in the output which are not present in the original signal.[8] Under such conditions the output sound pressure is not a faithful replica of the input signal. The extraneous frequencies present mask the original sounds thus reducing the distinctness of the speech. The maximum usable output obtainable from a given amplifier is limited by the amount of nonlinear distortion which can be tolerated.

Measurements of the amplitude distortion necessary to produce a detectable change in speech quality show that the amount of distortion which can be tolerated depends upon the band width of the amplifying system, the type of distortion (even or odd harmonics), and whether or not the distorted speech is compared directly with the undistorted speech.[9] With an upper cutoff frequency of 5,000 cycles per second it is found that from 12 to 17 per cent distortion can be introduced before a noticeable change in speech quality occurs. With an upper cutoff of 8,000 cycles per second the permissible distortion is reduced by approximately one half. For complex signals such as speech, the per cent distortion is defined as the amount of distortion produced by a pure tone having a peak value equal to the peak value of the complex wave. Satisfactory reproduction of speech will be obtained if the distortion is held below 15 per cent.

Gain Requirements

It is necessary to distinguish between output and gain. To be of practical use an instrument must develop the required output pressure at the ear when the source of sound is some distance away. The greater the amplification the less input signal the hearing aid will require to develop a given output pressure. At first thought it might appear that the maximum obtainable gain would be limited only by the number of stages of amplification which could be used in an instrument of wearable size. In practice there are two other factors which determine the maximum *usable* gain. The first of these is the surrounding noise level. Numerous measurements have shown that the extraneous noise level in the average quiet residence has an intensity level of about thirty decibels. In commercial buildings the noise level will be higher.[10] The effect of this extraneous noise level is to raise the threshold of hearing. A normal ear immersed in a noise level of 30 decibels would be unable to understand conversational speech unless the speech intensity level was greater than 30 decibels. In normal speech (at conversational distances) the loudest vowel sounds are 70 decibels above threshold and the weakest consonant sounds 30 decibels above threshold and thus they would be heard in spite of a noise level of 30 decibels. A hearing loss of 30 decibels would have the effect of eradicating the surrounding noise level but ordinary conversation still would be audible. If the source of sound were farther away, the desired sound would have a level less than the surrounding noise and no amount of amplification would help, since the noise and desired sound both would be amplified. The only solution is to have the desired signal louder than the background noise. Thus the auditor always must move close enough to the source of the desired sound to make its intensity level greater than that of the surrounding noise level. At conversational distances the speech sounds are located as shown in Figure 1. It is seen that the pressure of the loudest vowel sounds at the hearing-aid microphone will be 0.6 bar. To overcome the most severe case of deafness this pressure must be raised to 200 bars. This requires a pressure ratio or acoustical amplification of $200/0.6 = 333.3$ which corresponds to approximately 50 decibels. The other weaker sounds, assuming uniform amplification, will be raised by 50 decibels also.

If the surrounding noise level is lowered, the distance between speaker and

listener can be increased and the speech still will be above the noise level. The speech intensities arriving at the microphone will be less, and correspondingly greater gain will be required for the same sound-pressure output. On the other hand, if the noise level is increased, the distance between speaker and listener must be decreased in order to raise the speech sounds above the surrounding noise. The speech pressure incident upon the microphone now will be greater and less gain will be required for a given sound-pressure output. Thus the maximum usable gain is determined by the surrounding noise level. Under average conditions of 30 decibels noise level the speech intensities would be as shown in Figure 1 and the maximum usable gain would be 50 decibels. In order to hear in any given noise level either the speaker must raise his voice to an intensity above the noise level or the distance between the speaker and listener must be decreased. In any event, for a given noise level the speech must have a definite sound pressure if it is to be heard. Since the distance between threshold and feeling is approximately 120 decibels, the maximum usable gain in decibels is

$$\text{Maximum usable gain} = 120 - (\text{noise level} + 40) = 80 - \text{noise level} \quad (2)$$

All quantities in the above expression are in decibels. Figure 2 is a graph of equation 2.

Acoustic Feedback

It previously was stated that, in practice, two factors limit the maximum usable gain. One of these has been shown to be the surrounding noise level. The second limiting factor is acoustic feedback. A hearing aid produces a sound-pressure output many times greater than the input pressure. If a portion of the output is fed back into the input in proper phase and magnitude, oscillation results. When acoustic feedback or "squealing" occurs, the instrument ceases to be of use to the user. Hearing-aid receivers are of the insert type. They are held in place at the ear by means of a plastic mold, the tip of which extends into the ear canal. With an ideal ear mold all of the sound pressure would be delivered to the ear drum. In practice, due to the imperfect fit of the ear mold a certain amount of acoustic energy may escape and find its way back to the microphone. If at any frequency the attenuation in the return path from receiver to microphone is less than the acoustical gain of the instrument, oscillation occurs.

When individually molded ear tips are used a gain of 60 to 70 decibels is ordinarily the maximum which can be had without feedback.

Computation of Acoustical Gain

The over-all acoustical amplification of a hearing aid will be affected by the characteristics of each of the component parts of the instrument.

It is customary to specify the output level of a microphone in terms of its open-circuit output voltage in decibels above a reference level of one volt per bar. Figure 3 shows the output of an uncased hearing-aid microphone of the crystal type as a function of frequency. When the microphone is enclosed in a case the response is altered somewhat by the acoustical properties of the case and this effect often can be used to advantage. The acoustical properties of the case are not included in the following analysis. Receiver output level can be expressed in decibels above a zero level of one bar per volt. The response characteristic of a crystal-type hearing-aid receiver is shown in Figure 4.

The response characteristics of the microphone and receiver may be combined into a single curve which then will show the ratio of output pressure to input pressure of the two units acting together. This ratio will be less than unity and, when expressed in decibels, is a negative number. The combined characteristic of the microphone of Figure 3 and receiver of Figure 4 is shown in Figure 5.

After the microphone and receiver have been selected, the electrical gain of the amplifier necessary for a specified acoustical gain can be determined.

In order to develop an expression for the over-all acoustical gain of microphone, amplifier, and receiver the following definitions are necessary.

Let

K_M = open-circuit output of microphone in volts per bar

K_R = output of receiver in bars per volt

$K_{MR} = K_M K_R$ = ratio of output pressure to input pressure of microphone and receiver with no amplification between

P_o = output pressure of receiver in bars

P_i = input pressure to microphone in bars

VA = voltage amplification of amplifier unit

$G = P_o/P_i$ = over-all acoustical gain

N_A = over-all acoustical gain in decibels

Then

$$P_o = (P_i)(K_M)(K_R)(VA) \quad (3)$$

and

$$G = P_o/P_i = (K_M)(K_R)(VA) = (K_{MR})(VA) \quad (4)$$

In decibels the gain is

$$N_A = 20 \log_{10} G = 20 \log_{10} (K_{MR}) + 20 \log_{10} (VA) \quad (5)$$

Letting

$N_{VA} = 20 \log_{10} VA$ and $N_K = 20 \log_{10} K_{MR}$ equation 5 becomes

$$N_A = N_{VA} + N_K \quad (6)$$

Knowing the desired over-all gain N_A and the combined characteristic N_K the necessary voltage amplification of the amplifier expressed in decibels is obtained from equation 6 as

$$N_A = N_{VA} - N_K \quad (7)$$

N_K is a negative quantity so the required electrical gain is greater than the desired acoustical gain by N_K decibels. The necessary electrical gain thus is established in terms of the desired acoustical gain and the characteristic of the microphone-receiver combination. For the microphone-receiver combination of Figure 5, $N_K = -33$ at 500 cycles per second. To achieve an acoustical gain of 50 decibels at 500 cycles per second would thus require a decibel voltage gain, N_{VA}, of 83.

Control of Frequency Response

It has been shown that in many instances selective amplification is desirable in a hearing aid. There are numerous methods for controlling the frequency response of an amplifier. Most of these are not applicable to hearing-aid use because of the additional circuit components necessary. In the hearing-aid industry it is common practice to secure frequency selectivity by using a number of interchangeable parts each having different response characteristics, or to manufacture a number of different models each with a different response. These methods have the disadvantage that a multiplicity of extra parts must be manufactured and stocked in order to meet the requirements of people with different types of deafness. A further disadvantage is that at the time of purchase it is often difficult to determine which combination eventually will give the most satisfactory results. It might seem that the best of a number of available instruments could be selected by a listening test. Experience has shown, however, that methods of fitting a hearing aid which comprise selecting one of a group of available characteristics

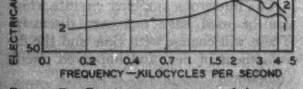

Figure 7. Frequency response of hearing-aid amplifier

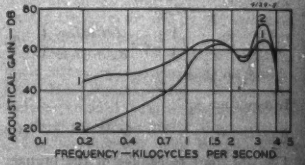

Figure 8. Acoustical gain of hearing aid

by listening test are not adequate. This is because the individual is accustomed to hearing sounds as they are rendered through his defective hearing mechanism. Thus, an instrument which makes sounds seem similar to those he is accustomed to hearing usually is chosen. As a result his impairment actually is exaggerated. It often is found that, after the user has become accustomed to an instrument, readjustment of the frequency response results in greater intelligibility. It is difficult to make such adjustments if they involve the exchange of an instrument or part of an instrument.

A novel method of controlling the frequency response of a hearing aid whereby the low frequencies can be attenuated while the high frequencies actually are accentuated now will be described.[11] This method is particularly suitable when used in conjunction with receivers which have a capacitative internal impedance, such as a crystal receiver. The method has the advantage that no interchangeable parts are necessary, and the variation in response is continuous throughout the range of operation.

The output stage of a hearing-aid amplifier usually is coupled to the receiver by means of a transformer or by means of a choke in order to obtain the largest possible output with a given "B" battery supply voltage. If a crystal receiver is used the internal capacity of the receiver and the inductance of the output choke form a parallel circuit with a resonant frequency determined by the LC product of the choke and receiver. The impedance of this parallel circuit is highest at resonance and maximum gain thus occurs at the resonant frequency. The frequency at which maximum gain occurs can be changed by varying the resonant frequency. The internal capacity of the receiver is fixed so the frequency of resonance must be changed by a variation of inductance. This could be done by tapping the coil but the number of resonant frequencies obtainable in this manner is limited.

Consider the circuit of Figure 6, in which the plate load of the output-tube V consists of the primary of transformer T in parallel with a receiver of internal capacity C_R. The secondary winding of T is connected to a variable resistance R_3. Considering the transformer by itself, the complex impedance looking into the primary is

$$Z_{12} = R_1 + \frac{(M\omega)^2 R_S}{R_S^2 + (L_S\omega)^2} + J\left\{ L_1\omega - \frac{(M\omega)^2 L_S\omega}{R_S^2 + (L_S\omega)^2} \right\} \quad (8)$$

$$= R_{12} + JL_{12}\omega \quad (9)$$

In equation 8,

$$R_S = R_2 + R_3 \quad (10)$$

The apparent resistance of the primary is thus R_{12} and apparent inductance is L_{12}.

Let

$$K = \frac{M}{\sqrt{L_1 L_2}} \quad (11)$$

and

$$N = N_1/N_2 \approx \sqrt{L_1/L_2} \quad (12)$$

Substitute equations 11 and 12 in 8 and obtain

$$Z_{12} = R_1 + \frac{K^2N^2R_S}{1+(R_S/L_S\omega)^2} + JL_1\omega\left\{ 1 - \frac{K^2}{1+(R_S/L_S\omega)^2} \right\} \quad (13)$$

In terms of the coefficient of coupling, K, and the turn ratio, N, the apparent resistance looking into the primary is

$$R_{12} = R_1 + \frac{K^2N^2R_S}{1+(R_S/L_S\omega)^2} \quad (14)$$

The apparent inductance is

$$L_{12} = L_1\left\{ 1 - \frac{K^2}{1+(R_S/L_S\omega)^2} \right\} \quad (15)$$

Equation 15 is the basis of the selective circuit under discussion. If the secondary winding of T is short-circuited $R_S = R_2$. By suitable transformer design $R_2/L_S\omega$ can be made small compared to unity. Under these conditions equation 15 reduces to

$$L_{12} = L_1(1-K^2) = L_S \quad (16)$$

The quantity L_S is the leakage inductance of the transformer referred to the primary winding. The coefficient of coupling, K, depends upon the physical arrangement of the two coils L_1 and L_2 and upon the magnetic circuit ou which they are wound. For coils wound on ferromagnetic cores, K can be made close to unity. L_S is then a few per cent of L_1.

With the secondary of T open-circuited ($R_3 = \infty$) equation 15 becomes

$$L_{12} = L_1 = \text{self-inductance of primary winding} \quad (17)$$

From equations 16 and 17 it is seen that any inductance value between L_1, the self-inductance of the primary winding, and L_S, the leakage inductance, can be obtained merely by varying the resistor R_3.

In the circuit of Figure 6 the primary of T is shunted by C_R, so the amplifier stage may be tuned to different resonant frequencies by means of a single variable resistor. Because of the resistance term, R_{12}, the resonance curves are very broad. The highest resonant frequency obtainable is

$$f_h = \frac{1}{2\pi\sqrt{L_S C_R}} = \frac{1}{2\pi\sqrt{L_1(1-K^2)C_R}} \quad (18)$$

The lowest resonant frequency obtainable is

$$f_l = \frac{1}{2\pi\sqrt{L_1 C_R}} \quad (19)$$

The ratio of these two frequencies is

$$f_h/f_l = \frac{2\pi\sqrt{L_1 C_R}}{2\pi\sqrt{L_1(1-K^2)C_R}} = \frac{1}{\sqrt{1-K^2}} \quad (20)$$

Thus any desired ratio of f_h/f_l can be obtained by providing the proper coefficient of coupling. The frequency response of the amplifier then can be controlled by varying R_3.

Performance of a Particular Hearing Aid

The curves of Figure 7 show the electrical response of a three-tube hearing-aid amplifier. The last stage of the amplifier uses the method previously described for varying the frequency response. Curve 1 is for R_3 open-circuited and curve 2 is for R_3 short-circuited. Any response characteristic lying between the two curves can be obtained by varying control R_3. Figure 8 shows the over-all acoustical amplification of a three-tube hearing aid having the electric gain shown in Figure 7. This instrument uses the microphone and receiver combination of Figure 5. Curve 1 of Figure 8 is obtained with the frequency control resistor, R_3, open-circuited. Curve 2 is obtained with the control resistor in the short-circuited position. The two curves indicate the maximum variation in response which is obtainable with this particular instrument. These curves were obtained using a 30-volt "B"-battery supply. At a frequency of 1,000 cycles per second an output pressure of 350 bars can be obtained with less than five per cent distortion when using a 30-volt supply.

Increasing the plate supply to 45 volts increases the gain by six decibels and provides approximately twice as much output pressure.

For methods of measuring the performance of hearing aids, reference 12 should be consulted.

Conclusion

This paper correlates the fundamental characteristics of speech and hearing which are of importance in the development and design of hearing aids. It is shown that often a particular type of selective amplification is beneficial. A novel method of obtaining this type of amplification is described. It is pointed out that certain factors external to the hearing aid determine the maximum performance obtainable. A method of computing the acoustical amplification of a hearing aid is given. Response curves of a three-tube hearing aid using a crystal-type microphone and receiver are shown.

The numerous amplifier circuits which can be used have not been discussed. These will change with time and the development of new and improved circuit components.

Future possibilities for improvement lie in the establishment of more accurate

Surface Heating by Induction

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Synopsis: Induction heating offers a method for heating of electrical conductors such as steel, brass, graphite, by exposing them to a varying magnetic field.

The application of induction heating to melting, forging, surface hardening, and other uses is becoming increasingly common, resulting in a mounting interest for a physical concept of the heating effect itself. This effect has been previously analyzed by means of partial differential equations whose solutions are Bessel functions.[1] It is the object of this paper to analyze the induction-heating effect by using concepts commonly applied to a-c engineering without involving differential equations. It was found that ordinary vector diagrams lead to quantitative expressions for the penetration of the magnetic field into the charge, for the distribution of eddy currents and generated heat, as well as for the impedance of the loaded inductor.

The analysis is limited to the heating of a body of cylindrical shape, surrounded by a uniform alternating magnetic field; this limitation is the same as commonly applied when partial differential equations are used for the analysis.

Another limitation is introduced by the assumption that the depth of penetration is very small compared to the radius of the charge. This assumption greatly simplifies the mathematical treatment without sacrifice to the physical concept. If the depth of penetration is five per cent of the radius of the charge, the expression for the generated heat in the load will deviate only 3.6 per cent from the evaluation by Bessel functions; for smaller depths of penetration the deviation approaches zero.

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THE generation of heat within the iron core of a power transformer is termed the core loss, which is one form of induction heating. It is customary to divide the core loss into hysteresis and eddy-current loss. The hysteresis loss is a characteristic property of ferromagnetic materials, whereas the eddy-current loss is an I^2R loss due to current circulation in the material, resulting from electromotive forces induced by the varying induction. Replacing the iron of the core by a nonmagnetic metal will eliminate the hysteresis loss, but eddy currents will still be induced and heat generated. Hence, magnetic as well as nonmagnetic metals respond to induction heating.

When the frequency of the alternating magnetic flux is increased, hysteresis and eddy-current losses increase. The eddy-current loss, however, increases at a much greater rate than the hysteresis loss. At frequencies of the order of 10,000 cycles and more the eddy-current loss is predominant and the hysteresis loss is probably negligible.[2]

Among fields of application for induction heating are melting, forging, surface hardening, brazing, and soldering.[3,4,5] Induction heating is characterized by high concentration of heat per unit volume and close control of the transmitted heat. It is particularly suitable for surface hardening because the heat-producing eddy currents have a tendency to flow next to the surface of the charge. If a shaft is heated to hardening temperature at its surface zone only and is subsequently quenched, then only the surface zone hardens while its core remains soft. This distribution of hardness is often desirable. It gives the shaft a hard wear-resistant surface, whereas the core remains soft and thus avoids brittleness attendant to hardness.

The application of highly concentrated heat for surface hardening and forging shortens the heating time. This is important not only because of the saving of time in itself, but also because a short heat interval prevents or minimizes scale formation.

Although the heat is generated in the surface layer, the entire body of a charge can be heated if so desired. This is done simply by continued application of power, the heat being conducted thermally to the interior.

The Magnetic Field of the Air-Core Inductor

In order to heat a charge, it is placed inside a helical coil,[6,7] the inductor, the latter being energized from a high-frequency generator (Figure 1). Various types of high-frequency generators are on the market, such as rotary motor generators, electronic-tube oscillators, and spark-gap oscillators.[8,9,10] The frequencies for induction heating range from 60 cycles up to several megacycles. The generator energizes the inductor, thus producing an alternating magnetic flux. The latter induces electromotive forces within the charge, comparable to the induction of the voltage in the secondary of a transformer. The electromotive forces cause currents, the so-called eddy currents, to flow through the charge. The heating effect is the result of I^2R losses due to the eddy currents in combination with the electrical resistance of the charge.

It is assumed that the charge will be exposed to a uniform alternating magnetic field. Such a field is produced by a solenoid of infinite length, part of which is shown in Figure 2. The magnetic field intensity outside of the solenoid is zero; this is plausible, remembering that the return flux outside of the solenoid spreads over an infinitely large area, thus reducing the flux density to zero.[11]

Positive directions were assigned to the magnetic field intensity and the current. They are shown by arrows parallel to the axis of the inductor and by the head and tail symbols, respectively, indicating a right-hand system. For alternating magnetic intensities and currents the arrows show the direction of the instantaneous values, provided the latter appear positive in their respective vector diagrams.

For an infinitely long inductor and charge, which will be assumed in all of the following considerations, the field

methods of fitting hearing aids to the individual's specific needs and in the use of two-channel or binaural hearing aids.

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distribution is the same for any cross section perpendicular to its axis. It is, therefore, permissible to analyze only a limited height of inductor and charge. The magnetic-field and eddy-current distribution thus obtained will be representative for the entire height of inductor and charge. The height of the section under consideration will be limited arbitrarily to one centimeter.

The magnetic-field intensity, henceforth abbreviated magnetic intensity, follows from (see Appendix VII for symbols):

$$H = 0.4\pi In \tag{1}$$

If the current I is alternating, the magnetic intensity H is also alternating

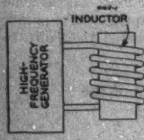


Figure 1. General arrangement of inductor and charge

and in time phase with the current I. Equation 1 can be rewritten

$$\boldsymbol{H} = 0.4\pi \boldsymbol{I} n \tag{2}$$

The boldface letters $\boldsymbol{H}$ and $\boldsymbol{I}$ designate vector quantities. The letters H and I signify the absolute values of the vectors. The instantaneous values h and i are obtained by projecting the vectors $\boldsymbol{H}$ and $\boldsymbol{I}$, which are standing still, on the time base T (see Figure 3) which rotates clockwise with an angular velocity:

$$\omega = 2\pi f \tag{3}$$

The location of the time axis T for the time $t=0$ is coinciding with vectors $\boldsymbol{I}$ and $\boldsymbol{H}$. The angle α between $\boldsymbol{I}$ and T is

$$\alpha = \omega t \text{ in radians} \tag{4}$$

where t is the time lapse from coincidence of T with $\boldsymbol{H}$ until T reaches the position shown in Figure 3. The quantities are positive for $-\frac{\pi}{2} < \alpha < \frac{\pi}{2}$, they are negative for $\frac{\pi}{2} < \alpha < \frac{3\pi}{2}$.

Screening Effect

Suppose the inductor (Figure 4) is energized by a constant alternating current, an alternating field intensity H_0 will result, which is constant over the whole cross section of the infinitely long inductor. A thin-walled tubular metallic charge A is now inserted coaxially. The variable magnetic flux surrounded by the charge induces voltages and currents in the charge in the same manner as in the secondary of a transformer, consisting of one turn which is short-circuited.

It is convenient to assume the positive directions of both inductor and charge current in the same right-hand-system direction, as indicated by the symbols in Figure 4.

Similar to the current I in the inductor, the current I_A circulating circumferentially in the infinitely long charge produces a magnetic intensity ΔH_0 which is constant throughout the space surrounded by the charge and which is zero for any point outside. The resulting field intensity at any instant can be regarded as a result of superposing the magnetic intensities caused by the currents in inductor and charge. The magnetic field intensity H_1 in the space surrounded by the charge is

$$H_1 = H_0 + \Delta H_0 \tag{5}$$

where H_0 is the magnetic intensity produced by the inductor current alone and

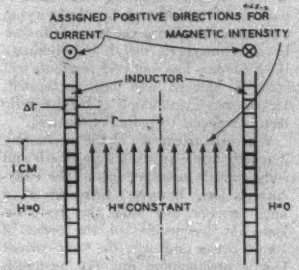


Figure 2. Magnetic intensities of infinitely long empty air-core inductor

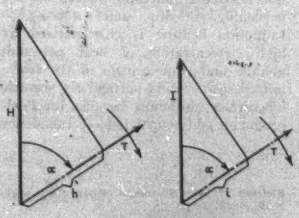


Figure 3. Vector diagrams in general

ΔH_0 the magnetic intensity produced by the charge current alone. In analogy to equation 1 and for $n = 1$

$$\Delta H_0 = 0.4\pi I_A \tag{6}$$

The induction B_1 in the space surrounded by the charge is

$$B_1 = \mu H_1 \tag{7}$$

and the magnetic flux Φ_1 surrounded by the charge is

$$\Phi_1 = B_1 a^2 \pi = \mu H_1 a^2 \pi \tag{8}$$

Φ_1 and H_1 are parallel vectors. The electromotive force E_A generated in the charge A by flux Φ_1 is lagging 90 degrees behind it (Figure 5). Overcoming the resistance of the current path, E_A causes the flow of current I_A, which is in phase with E_A. ΔH_0 is parallel to I_A. H_0 follows from equation 5 as $0P$. The flux Φ_0 between inductor and charge is in phase with H_0.

An inspection of the vector diagram of Figure 5 reveals:

1. The magnetic intensity H_0 outside the charge is reduced in intensity to H_1 as it penetrates the charge. This effect which is due to the circulation of eddy currents in the charge is often called screening effect.

2. The currents in the charge cause a time lag between the magnetic intensities, resulting in a lag of the flux Φ_1 surrounded by the charge, with respect to the flux Φ_0 outside of the charge.

Solid Cylindrical Charge

General Considerations

A solid charge can be considered made up by a large number of thin-walled tubular sleeves which are telescoped into each other; the eddy-current heating of a solid charge will be approached by considering the current distribution in the individual thin-walled sleeves, reducing the thickness of the latter toward zero.

Judging from the case of a single thin-walled sleeve, one is led to expect that the magnetic intensity H_0 will be reduced a certain percentage while penetrating the sleeve S_1 (Figure 6) and that it will emerge from sleeve S_1 as the intensity H_1; it can also be expected that the emerging field intensity H_1 will lag behind the entering intensity H_0. The vectors of the magnetic intensities are shown in larger scale in Figure 7. The

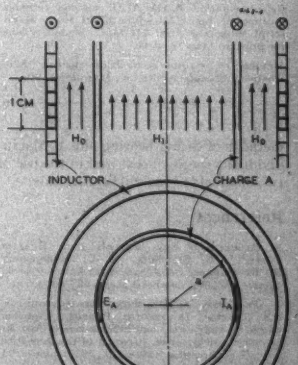


Figure 4. Field distribution in inductor containing a tubular charge of small wall thickness

angle $01P$ between ΔH_0 and H_1 (Figure 7), however, cannot be expected to remain 90 degrees as in the case of Figure 5, because the current I_1 flowing in sleeve S_I is no longer determined by the electromagnetic action of sleeve S_I only, but also by the electromagnetic action of all the other sleeves S_{II}, S_{III} . . . . . inside of S_I. The current I_1 in S_1 is a function of the total flux surrounded by S_1, which in turn is a function of the different currents in all the sleeves. All that can be expected is that the magnetic intensity H_0, by penetrating sleeve S_I of the thickness Δr, will emerge as the intensity H_1, lagging $\Delta\alpha$ behind H_0, and being reduced in magnitude by a definite percentage of its entering value. The magnetic intensity H_1 then enters sleeve S_{II}. If the wall thickness is the same for S_I and S_{II}, it can be assumed that the emerging magnetic intensity H_2 will lag by the same angle $\Delta\alpha$ behind H_1 as H_1 was lagging behind H_0 in sleeve S_I. The ratio of reduction of H_1 to H_2 can be assumed to be equal to H_0 to H_1. These assumptions are justified by leading to interdependent systems of magnetic intensities and fluxes, electromotive forces, and currents, which fulfill all physical requirements.

Vector Diagram of Magnetic Intensities

A vector diagram embodying the foregoing assumptions is shown in Figure 7. Let

$$H_1/H_0 = H_2/H_1 = \ldots . H_m/H_{m-1} = q = \text{constant} \quad (9)$$

$$\sphericalangle 0P1 = 1P2 = 2P3 = \ldots . = \Delta\alpha = \text{constant}$$

It follows that the triangles $P01$, $P12$, $P23$, ... are similar (two homologous sides and one included angle $\Delta\alpha$). These geometric relations are mathematically expressed by

$$H_m = H_0 \varepsilon^{-(m\Delta\alpha)\cot\beta} \qquad \alpha \text{ in radians} \quad (10)$$

as shown in Appendix I. If the phase angle of H_m with respect to H_0 is α, then

$$\alpha = m\,\Delta\alpha \quad (11)$$

and

$$H_m = H_0 \varepsilon^{-\alpha\cot\beta} \qquad \alpha \text{ in radians} \quad (12)$$

indicating a logarithmic spiral as locus for the magnetic intensity.

Vector Diagram of Magnetic Fluxes

The flux Φ_1 contained within the body of sleeve S_1 is

$$\Phi_1 = B_1 \text{ area} = \mu H_1 [(\Delta r/2)(a - \Delta r/2)\pi] \quad (13a)$$

likewise

$$\Phi_M = \mu H_M \left[(\Delta r/2)\left(a - \frac{2m-1}{2}\Delta r\right)\pi \right] \quad (13m)$$

Subscripts I and M refer to the quantities existing in the middle of the body of the first and mth sleeve, respectively, whereas subscripts 1 and m refer to the quantities at the lateral inner surface of the first and mth sleeve, respectively.

It can be seen from Figure 7 that the magnetic intensities and thus the inductions decline very rapidly as the magnetic field penetrates into the charge. The variation of the areas over which the fluxes are spread can be neglected if the magnetic intensity rapidly decreases as it penetrates the charge. Thus

$$\Phi_1 = H_{1\mu}\,\Delta r 2a\pi \quad (14a)$$

$$\Phi_{II} = H_{II\mu}\,\Delta r 2a\pi \quad (14b)$$

$$\Phi_M = H_{M\mu}\,\Delta r 2a\pi \quad (14m)$$

Adding the fluxes Φ_I, Φ_{II}, Φ_{III} . . . . . vectorially (by using equations 14a, 14b, and 14m in combination with Figure 7), the vector sum follows a logarithmic spiral which is similar to the locus for the magnetic intensity as proved in Appendix II. The spiral for the fluxes is shown in Figure 8.

The total magnetic flux Φ inside of the charge is the vector sum of all individual fluxes Φ_I, Φ_{II}, Φ_{III} . . . . . For a sleeve of infinitesimal thickness the angle $\Delta\alpha = 0$ and the phase angle between total flux Φ inside the entire charge and the magnetic intensity H_0 between inductor and charge is

$$\beta = 45 \text{ degrees} \quad (21)$$

Since inductor current I and H_0 are in phase, the angle between I and Φ is also 45 degrees (Figure 9).

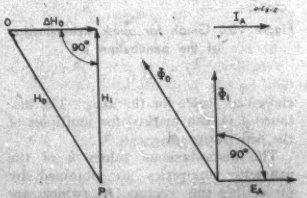


Figure 5. Vector diagram for inductor with tubular charge of small wall thickness

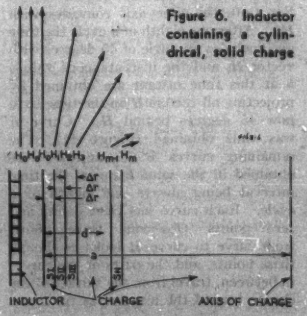


Figure 6. Inductor containing a cylindrical, solid charge

Power Factor of Charge

The total flux Φ induces a voltage E in the inductor which is 90 degrees lagging behind Φ and 45 additional degrees behind the inductor current I. Voltage E consists of two components E_R and E_X of equal magnitude. E_R is in counterphase with I and reflects the watt power consumed by the charge. E_X is lagging 90 degrees behind the current and indicates that the charge consumes inductive power as well. Due to the equality in magnitude of E_R and E_X, the load consumes as much watt power as wattless inductive power. Therefore,

Figure 7. Vector diagram of magnetic intensities

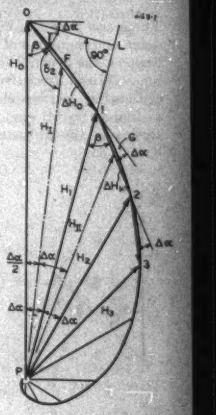
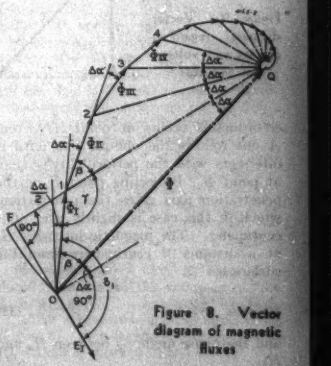


Figure 8. Vector diagram of magnetic fluxes



Power factor of charge = cos 45 degrees = 0.707 inductive (22)

Penetration of the Magnetic Field

The total magnetic flux Φ within the boundaries of the charge is evaluated in Appendix III:

$$\Phi = B_0(2a\pi)\rho \quad (30)$$

where B_0 is the induction in the space between inductor and charge. If the

induction B_0 would penetrate into the charge to a depth of p centimeters, without being attenuated, the magnitude of the flux thus obtained would be equal to the magnitude of the actual flux Φ. For this reason the factor p is often called equivalent depth of the magnetic-field penetration, or shortly penetration. It follows from Appendix III:

$$p = \frac{1}{2\pi}\sqrt{\frac{\rho 10^9}{2\mu f}} \qquad (31)$$

The graph shown in Figure 10 serves for quick determination of the penetration p. Suppose the penetration should be found for soft iron (resistivity $\rho = 10^{-4}$ ohm-centimeter, permeability $\mu = 1{,}000$) at a frequency of one kilocycle. Intersection of the frequency and resistivity

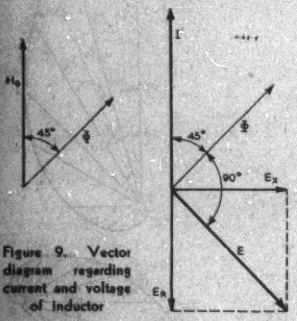


Figure 9. Vector diagram regarding current and voltage of inductor

co-ordinates occurs at point A. From A one follows the oblique line until it intersects with the permeability system at point B. Projecting point B on the penetration axis gives the penetration, which in this case is slightly over 10^{-2} centimeter. The magnetic intensity H_d at a distance d centimeters from the surface is

$$H_d = H_0 \epsilon^{-\frac{d}{p\sqrt{2}}} \qquad (35)$$

and the phase angle α_d between H_d and H_0

$$\alpha_d = d/(p\sqrt{2}) \text{ in radians} \qquad (36)$$

Field Propagation Inside the Charge

Returning to the vector diagram of Figure 7, the various vectors H_0, H_1, H_2 represent the magnetic intensities at definite distances from the surface of the charge. These distances d follow from equation 36. In the vector diagram of Figure 7 the angle $\Delta\alpha$ was made 15 degrees, which is identical with $\pi/12$ radians. The distance at which vector H_1 represents the magnetic intensity can be obtained from equation 36:

$$d = \alpha_d p\sqrt{2} = (\pi/12)p\sqrt{2} \text{ in centimeters}$$

Conversely, the magnitude and phase of the magnetic field for any given distance d from the surface can be obtained by computing α_d from equation 36, and subtending α_d from H_0 to intersect the logarithmic spiral.

Using the vector diagram of Figure 7, a graph of the instantaneous distribution of magnetic intensities can be plotted (Figure 11). The plane of the graph can be considered as a partial lateral section through the cylindrical charge. The graph is limited on the left-hand side by the surface contour of the charge. The axis of the charge is parallel to the contour off to the right. The abscissa axis can be viewed as one radius of the charge. In order to generalize the graph, relative values $d/(p\sqrt{2})$ and h/H_0 were

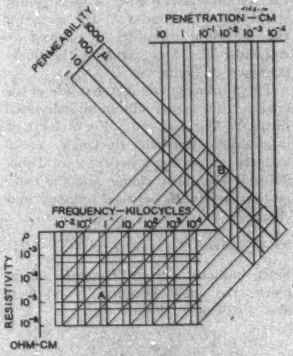


Figure 10. Graph for quick determination of the penetration p

chosen as scales for the axes. The distance d is also marked for multiples of the penetration p.

The instantaneous values h of the magnetic intensities are obtained by projecting the vectors H (which are standing still) on a common time axis T. The time axis rotates clockwise and makes one revolution during each cycle of the high-frequency current (equation 3). For $t = 0$, the time axis coincides with H_0. After one eighth of a cycle the time axis includes an angle of 45 degrees with vector H_0 and the instantaneous values h at this time instant are obtained by projecting all vectors H on the time axis, now 45 degrees behind H_0. Curve A was thus obtained (Figure 11). The remaining curves B, C, and D were obtained in the same manner, the time interval being always one eighth of a cycle. Each curve has crest points and zero points. Observing these points from curve to curve, it looks as though these points, and the parts of the curves in between, travel from the surface of the charge toward the interior, as time goes on. It will also be observed that the height of the wave decreases as it penetrates the charge. It is therefore possible to view the field distribution inside of the charge as the result of an electromagnetic wave entering the charge at its surface and being attenuated as it proceeds.

Density of Eddy Currents

The current density K_0 in the surface layer follows from Appendix IV.

$$K_0 = In/p \text{ amperes per square centimeter} \qquad (37)$$

In general, the current density depends on the flux with which the current filament is interlinked and the resistance of the path; the latter is assumed constant. Hence the current densities can be expressed by the same exponential function as the interlinking fluxes and the magnetic intensities, respectively (equations 12 and 21). The current density K_d at the distance d from the surface

$$K_d = K_0 \epsilon^{-\frac{d}{p\sqrt{2}}} = (In/p)\epsilon^{-\frac{d}{p\sqrt{2}}} \qquad (37a)$$

The generation of heat per unit volume at any depth d is:

$$w_d = {}^1/_2 K_d{}^2 \rho = {}^1/_2 (In/p)^2 \rho \epsilon^{-\frac{d\sqrt{2}}{p}} \text{ watts per cubic centimeter} \qquad (37b)$$

Plotting the function $\epsilon^{-\frac{d\sqrt{2}}{p}}$ in Figure 12 discloses the rapid reduction of heat generation with increasing distance from the surface. The concentration of the eddy currents and hence the generation of heat next to the surface of the charge is called skin effect. The heat generated in a zone reaching to a depth of $3p$ is 98.5 per cent of the total generated heat.

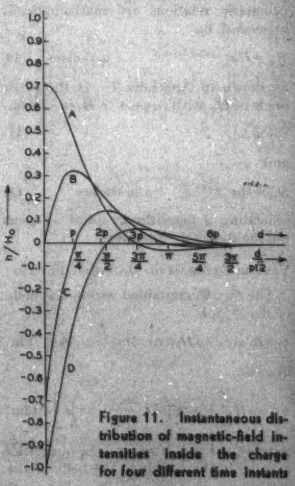


Figure 11. Instantaneous distribution of magnetic-field intensities inside the charge for four different time instants

Since the penetration p depends on the frequency of the inductor current (equation 31) one can vary the thickness of the heated zone by controlling the frequency. The case thickness can be reduced by increasing the frequency, conversely lowering the frequency will increase the depth of the heated zone as it is desirable in forging and melting applications.

Power Transfer and Impedance of Loaded Inductor

The power P delivered to the charge per centimeter axial length is shown in Appendix V.

$$P = 4\pi^2 a\,(I_{a0}n)^2\sqrt{\mu f\rho}\,10^9\,10^{-9} \text{ watts per centimeter axial length of charge} \quad (38)$$

All other conditions remaining the same, increasing the frequency increases the rate of heating. A material with greater resistivity will generate more heat, provided the depth of penetration is much smaller than the radius of the charge (see synopsis). Moreover, a material with a positive temperature-resistivity coefficient, will generate heat in increasing measure as it warms up.

Due to permeability, ferromagnetic materials will heat more rapidly than nonferrous materials of the same resistivity. However, when the critical temperature is reached ferromagnetism disappears and the permeability drops to unity. Thus, the heating of ferromagnetic materials is greatly reduced when the critical temperature is obtained.

As previously pointed out, the charge consumes watt power and a numerically equal amount of wattless inductive power. The inductor presents itself with a certain impedance, which is called the referred impedance Z_a of the load (charge); in addition the inductor will have a self-impedance Z_b consisting of the high-frequency impedance of its own winding and a reactance due to the magnetic field in the interspace between inductor and charge.

The above considerations lead to the expression for the referred resistance R_a of the load, as shown in Appendix VI.

$$R_a = 4\pi^2 a n^2\sqrt{\mu f\rho}\,10^9\,10^{-9} \text{ ohms per centimeter axial length of charge} \quad (39)$$

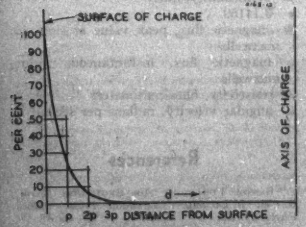


Figure 12. Relative heat generation as a function of the distance d from the surface

Since watt and wattless power are numerically equal, the referred reactance

$$|X_a| = R_a$$

and the referred impedance

$$Z_a = R_a + jX_a = R_a(1+j)$$

The high-frequency resistance R_b of the inductor can be approximated by using equation 39. For a water-cooled copper inductor the resistance R_b is according to Appendix VI:

$$R_b = 1.8\,b\sqrt{f}\,n^2(c_1/c_2)10^{-9} \text{ ohms per centimeter axial length of charge} \quad (40)$$

The losses in the inductor increase with its radius b. In order to obtain high efficiency of power transfer, the radius of the inductor should not be larger than necessary. Hence, the clearance between inductor and charge should be kept to a minimum.

Since watt and wattless power are numerically equal, the referred reactance of the inductor due to the field within the boundaries of the conductors is:

$$|X_b| = R_b$$

Hence the impedance

$$Z_b = R_b + jX_b = R_b(1+j)$$

The reactance X_0 due to the magnetic field in the interspace between inductor and charge is shown in Appendix VI.

$$X_0 = 8\pi^2 f\,(b^2 - a^2)n^2\,10^{-9} \text{ ohms per centimeter axial length of charge} \quad (41)$$

The total impedance Z of the loaded inductor is therefore:

$$Z = (R_a + R_b) + j(R_a + R_b + X_0) \text{ ohms per centimeter axial length of charge} \quad (42)$$

Appendix I

The ratio of two consecutive magnetic intensities from equation 10 is

$$H_m = H_0\epsilon^{-m\Delta\alpha\cot\beta}$$

$$H_{m-1} = H_0\epsilon^{-(m-1)\Delta\alpha\cot\beta}$$

Therefore:

$$H_m/H_{m-1} = \epsilon^{-\Delta\alpha\cot\beta} = q \quad (10a)$$

which is constant for positive, integral m.

$$q = H_1/H_0 = (\sin\beta)/\sin(\beta+\Delta\alpha)$$

$$= 1 - \frac{\sin(\beta+\Delta\alpha) - \sin\beta}{\sin(\beta+\Delta\alpha)}$$

$$= 1 - \frac{2\cos(\beta+\Delta\alpha/2)\sin(\Delta\alpha/2)}{\sin(\beta+\Delta\alpha)}$$

For sleeves of infinitesimal wall thickness

$$\sin\Delta\alpha/2 = \Delta\alpha/2 \quad (10b)$$

and

$$\beta + \Delta\alpha/2 = \beta + \Delta\alpha = \beta \quad (10c)$$

hence

$$q = 1 - \Delta\alpha\cot\beta \quad (10d)$$

The same result is obtained by using equations 10 and 10a:

$$\epsilon^{-\Delta\alpha\cot\beta} = 1 - \Delta\alpha\cot\beta \text{ for } \Delta\alpha\cot\beta \ll 1$$

Appendix II

Vector 01 representing Φ_1 (Figure 8) is parallel to H_1 of Figure 7 and determined by equation 14a. Vector 12 is parallel to H_{II} and determined by equation 14b. Hence

$$\Phi_{II}/\Phi_I = H_{II}/H_I \quad (15)$$

H_I connects midpoint F of 01 (Figure 7) to P; H_{II} was obtained likewise. Triangles $0PF$ and $1PG$ are similar (two homologous sides and one included angle β) and hence:

$$H_{II}/H_I = H_I/H_0 \quad (16)$$

From equations 9, 15, and 16:

$$\Phi_{II} = \Phi_I H_{II}/H_I = \Phi_I H_I/H_0 = \Phi_I Q \quad (17)$$

Point Q (Figure 8) was obtained by subtending the angle β from Φ_I and Φ_{II} (Figure 8).

$$\gamma = 180° - \Delta\alpha - \beta$$

$$\sphericalangle 1Q0 = 180 - \beta - \gamma = 180 - \beta - 180 + \Delta\alpha + \beta = \Delta\alpha° \quad (18)$$

Triangles $01Q$, $12Q$, $01P$, and $12P$ are similar. If another similar triangle $23Q$ is based on $2Q$, it can be shown in the same manner that 23 represents vector Φ_{III}. The sum of the first three individual fluxes Φ_I, Φ_{II}, Φ_{III} is $Q3$. The remaining individual fluxes and their sum can be determined by a repetition of the same procedure. The triangles become progressively smaller and finally degenerate in point Q. Line $0Q$ therefore represents the vector sum of all fluxes, and is denoted Φ. It is the total magnetic flux within the boundaries of the charge. Due to the similarity of all triangles involved, curve $01234\ldots P$ (Figure 7) is similar to $01234\ldots Q$ (Figure 8).

The electromotive force E_I induced in sleeve S_I is due to the action of all the fluxes Φ_{II}, Φ_{III}, ... , surrounded by sleeve S_I. The vector sum of these fluxes is $1Q$ (Figure 8). E_I is lagging 90 degrees behind $1Q$. Angle δ_1 between E_I and Φ_I is

$$\delta_1 = \beta + \Delta\alpha + 90° \quad (19)$$

Angle δ_2 between ΔH_0 and H_I (Figure 7) can be expressed

$$\delta_2 = 180° - \beta - \Delta\alpha/2 \quad (20)$$

ΔH_0 is in phase with I_I (equation 6) and H_I is in phase with Φ_I, equation 14a, so that δ_2 is also the angle between Φ_I and I. Remembering that I_I and E_I are in phase, angle δ_2 is the angle between Φ_I and E_I as well. This angle has been previously denoted with δ_1. Therefore from equations 19 and 20:

$$\delta_1 = \delta_2$$

$$\beta + \Delta\alpha + 90° = 180 - \beta - \Delta\alpha/2$$

$$\beta = 45° - 3\Delta\alpha/4$$

For infinitesimal thickness of the sleeve, $\Delta\alpha$ disappears and

$$\beta = 45 \text{ degrees} \tag{21}$$

Appendix III

The electromotive force E_0 in the surface zone of the charge is a function of the total flux Φ:

$$e_0 = -\frac{d\varphi}{dt} 10^{-8}$$

hence the crest value

$$E_0 = 2\pi f \Phi 10^{-8} \tag{23}$$

The current I_0 in the surface layer

$$I_0 = E_0 / R_0 \tag{24}$$

where R_0 is the resistance of the surface layer per centimeter axial length of the charge

$$R_0 = \frac{2a\pi}{\Delta r \cdot 1\ cm} \rho \tag{25}$$

From equations 23, 24, and 25,

$$I_0 = 2\pi f \Phi 10^{-8} \frac{\Delta r}{2a\pi\rho} = \frac{\Delta r}{a} \frac{f}{\rho} \Phi 10^{-8} \tag{26}$$

$$\Delta H_0 = 0.4\pi I_0 = 4\pi (f/\rho)(\Delta r/a)\Phi 10^{-9} \tag{27}$$

Because of the similarity of triangles $0P1$ (Figure 7) and $0Q1$ (Figure 8)

$$\Phi / \Phi_1 = H_0 / \Delta H_0 \tag{28}$$

For infinitesimal sleeve thickness $H_0 = H_1$, moreover, substituting for H_1 from equation 14a and for ΔH_0 from equation 27, one obtains from equation 28

$$\frac{\Phi}{\Phi_1} = \frac{\Phi_1 / \mu \Delta r 2a\pi}{4\pi (f/\rho)(\Delta r/a)\Phi 10^{-9}} = \frac{1}{\Delta r} \sqrt{\frac{1}{8\pi^2} \frac{\rho 10^9}{\mu f}} \tag{29}$$

Substituting for Φ_1 from equation 14a and for $B_1 = B_0$:

$$\Phi = B_0 2a\pi \left(\frac{1}{2\pi} \sqrt{\frac{\rho 10^9}{2\mu f}} \right) = B_0 2a\pi p \tag{30}$$

where

$$p = \frac{1}{2\pi} \sqrt{\frac{\rho 10^9}{2\mu f}} \tag{31}$$

Figure 8 reveals that

$$\Phi_1 / \Phi = (\sin \Delta\alpha) / \sin (\beta + \Delta\alpha)$$

Considering equations 10b, 10c, and 21,

$$\Phi_1 / \Phi = \Delta\alpha \sqrt{2}$$

which combined with equation 29, gives

$$\Phi_1 / \Phi = \Delta\alpha \sqrt{2} = \Delta r / p \tag{32}$$

The magnetic field by penetrating sleeve by sleeve accumulates for each sleeve thickness Δr a phase displacement of $\Delta\alpha$. Penetrating m sleeves

$$d = m \Delta r \tag{33}$$

The phase angle α follows from equation 11

$$\alpha = m \Delta\alpha$$

Using equations 11 and 33 in equation 32,

$$\Delta r / \Delta\alpha = d/\alpha = p\sqrt{2} \tag{34}$$

Substituting equation 34 in equations 12 and 21 and using the subscript d instead of m, indicating the magnetic intensity at the distance d from the surface,

$$H_d = H_0 \epsilon^{-\frac{d}{p\sqrt{2}}} \tag{35}$$

and the phase angle α_d between H_d and H_0 from equation 34

$$\alpha_d = \frac{d}{p\sqrt{2}} \text{ in radians} \tag{36}$$

Appendix IV

The current density K_0 in the surface layer

$K_0 = I_0$/cross section of path

Using equation 26 and substituting for Φ from equations 30 and 7,

$$K_0 = \frac{(f/\rho)(\Delta r/a)\mu H_0 2a\pi p\ 10^{-8}}{\Delta r \cdot 1cm}$$

$$= \frac{10}{4\pi} H_0 4\pi^2 \frac{2\mu f}{\rho} p\ 10^{-9}$$

Substituting from equation 31 for p,

$$K_0 = H_0 (10/4\pi)/p = (4\pi/10) I n (10/4\pi)/p$$

$$= In/p \tag{37}$$

Appendix V

Assigning the same radius a to the various sleeves of infinitesimal thickness (which is permissible without undue error for $p < a/20$), the total heat W:

$$W = 2a\pi \int_{d=0}^{a} w_d d(d) = (In/p)^2 p\pi a \times \int_{d=0}^{a} \epsilon^{-\frac{d\sqrt{2}}{p}} d(d)$$

$$W = (In/p)^2 p\pi \left(-ap/\sqrt{2}\right) \left(\epsilon^{-\frac{a}{p}\sqrt{2}} - 1 \right)$$

For $p < a/20$ $\quad \epsilon^{-\frac{a}{p}\sqrt{2}} \approx 0$

$$W = (In/p)^2 p\pi a p/\sqrt{2} = 4\pi^2 a (I_{eff} n)^2 \times \sqrt{\mu f \rho}\ 10^9\ 10^{-9} \tag{38}$$

Appendix VI

The referred resistance R_a follows from equation 38:

$$I_{eff}^2 R_a = 4\pi^2 a (I_{eff} n)^2 \sqrt{\mu f \rho}\ 10^9\ 10^{-9}$$

$$R_a = 4\pi^2 a n^2 \sqrt{\mu f \rho}\ 10^9\ 10^{-9} \text{ ohms} \tag{39}$$

For a copper inductor, using a rectangular water-cooled conductor, $\mu = 1$; the resistivity of the inductor at a temperature of 60 degrees centigrade $\rho = 2.04\ 10^{-6}$ ohm-centimeter, using these values in equation 39:

$$R_b = 1.8\ b\ n^2 \sqrt{f}\ (c_1/c_2)\ 10^{-6} \tag{40}$$

The flux Φ_0 in the interspace is:

$$\Phi_0 = 0.4\pi In (b^2 - a^2)\pi$$

$$e = -\frac{d\varphi_0}{dt} n 10^{-8} = -0.4\pi n^2 (b^2 - a^2)\pi \frac{di}{dt} 10^{-8}$$

$$E = 8\pi^2 n^2 f (b^2 - a^2) I\ 10^{-9} \text{ volts}$$

$$X_0 = E/I = 8\pi^2 n^2 f (b^2 - a^2) 10^{-9} \text{ ohms} \tag{41}$$

Appendix VII. Definitions of Symbols

a—radius of the charge, centimeters
B—induction, peak value of sinusoid, gausses
b—radius of the inside of the inductor, centimeters
c_1—winding pitch of the inductor, centimeters
c_2—height of the conductor, centimeters
d—distance of a point inside of charge to surface, centimeters
E—electromotive force, peak value of sinusoid, volts
e—electromotive force, instantaneous value, volts
f—frequency of inductor current, cycles per second
H—magnetic intensity, peak value of sinusoid, oersteds
h—magnetic intensity, instantaneous value, oersteds
I—current, peak value of sinusoid, amperes
I_{eff}—current, rms value, amperes
i—current, instantaneous value, amperes
j—$\sqrt{-1}$
K—current density, peak value of sinusoid, amperes per square centimeter
n—number of turns of inductor per centimeter axial length
P—power, average value, watts
p—penetration, centimeters
Δr—thickness of sleeve, centimeters
R_a—referred resistance of charge, ohms per centimeter axial length
R_b—high-frequency resistance of inductor, ohms per centimeter axial length of inductor
t—time, seconds
w—generated heat, average value, watts per cubic centimeter
X_0—reactance of inductor due to the magnetic field in the interspace between inductor and charge, ohms per centimeter axial length of inductor
Z—total impedance of loaded inductor, ohms per centimeter axial length of inductor and charge
$\alpha, \beta, \gamma, \delta$—angles, in degrees or radians, as noted
ϵ—base of natural logarithms, 2.71828
μ—permeability, unity
π—3.14159
Φ—magnetic flux, peak value of sinusoid, maxwells
φ—magnetic flux, instantaneous value, maxwells
ρ—resistivity, ohm-centimeters
ω—angular velocity, radians per second

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Induction Heating—Selection of Frequency

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MEMBER AIEE

THE general definition of induction heating is the use of eddy currents to raise the temperature of a conducting mass. Thus induction heating is an application of the theory of the eddy-current phenomenon.

This paper deals with the relation of frequency and kilovolt-ampere capacity as the basis for the selection of the frequency for a given heating service.

Charges. The body (or bodies collectively) to be heated is termed the charge. Charges in induction-heating practice are of three types, namely:

1. Charges of nonmagnetic material.

2. Charges of magnetic material. Maximum temperature below the critical temperature.

3. Charges of magnetic material. Maximum temperature above the critical temperature.

The Solid Cylindrical Charge. The shape of the charge is taken into account in analyses of the heating effect of eddy currents. However, the shape of the charge is not a factor in the principle involved. Hence a simple shape, the solid cylinder, is selected as the basis of this discussion.

The Transformer. The most effective arrangement of parts for induction heating is the charge inside a coil. An assembly of this type, less supports, for heating a charge to a temperature below the melting point of the material is shown in Figure 1.

This assembly is a form of transformer with these peculiar features:

(*a*). A closed secondary circuit formed in the charge.

(*b*). An open magnetic circuit. In some cases iron is added to the portion of the path of the magnetic flux that is outside of the charge. However, the general case is expressed by the term "coreless induction heating."

(*c*). The air gap between the primary and secondary circuits.

Circuit Equations. The equations of the circuits of the transformers previously noted are given in the appendix.

Basic Equations. The relation of the factors in the eddy-current phenomenon is given in the three equations which follow.

Reference dimension,

$$p = \frac{\sqrt{\rho 10^9}}{2\pi\sqrt{2}\sqrt{\mu f}} \text{ centimeters} \quad (1)$$

$$= \frac{3{,}560\sqrt{\rho}}{\sqrt{\mu f}} \text{ centimeters} \quad (1a)$$

$$\text{Index ratio, } \Delta = \frac{a}{p} \quad (2)$$

p = the radial dimension of the annular zone of the charge indicated in Figure 2

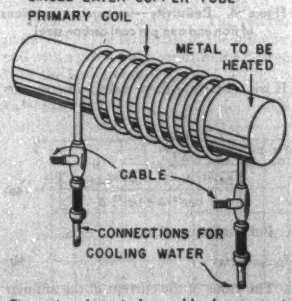

Figure 1. A typical assembly, less supports, for heating solids

ρ = the resistivity, ohm-centimeters^3, of the material of the charge

μ = the permeability of the material of the charge

f = frequency

a = the radius of the charge, centimeters

Rate of Heat Development. The rate at which heat is developed by eddy currents in a solid cylindrical charge is expressed by the equation:

$$P_{cm^3} = \left(\frac{1}{4\pi\sqrt{2}}\right)(H^2)\left(\frac{\sqrt{\mu f}\sqrt{\rho 10^9}}{a}\right)\times [F_r]\times 10^{-7} \quad (3)$$

P_{cm^3} = watts per cubic centimeter

H = the intensity of the alternating magnetic flux at the peripheral surface of the charge

$$[F_r] = \left[\frac{\text{ber}\,\Delta\,\text{ber}'\,\Delta + \text{bei}\,\Delta\,\text{bei}'\,\Delta}{\text{ber}^2\,\Delta + \text{bei}^2\,\Delta}\right]$$

Values of $[F_r]$ for a range of values of the index ratio are given in Figure 3.

Resistivity. The resistivities of metals have positive temperature coefficients. This characteristic is illustrated by Figure 4 for iron and carbon steel in the solid state. There is a marked increase of resistivity at the melting points of metals. The resistivities of steels in the molten state are within the range 150 to 200 microhm-centimeters cube. The value in each case depends on the analysis of the steel and its temperature.

The value of ρ to insert in equations 1, 2, and 3 is the value that corresponds to the maximum temperature of the charge.

Permeability. Values of μ are based on uniform distribution of magnetic flux. A feature of induction heating is nonuniformity of flux distribution. This and the fact that with alternating current the permeability changes during every cycle make uncertain the effective value of μ to insert in equations 1, 2, and 3 for type-2 charges. Generally it is assumed that the effective value of μ is some fraction of the saturation value. In any case the value of μ for calculations must be either estimated or determined by measurements.

The effect of the magnetic property in the batch heating of type-3 charges is an initial boosting of the rate of heat development. This effect lasts until the outer layer of the charge reaches the critical temperature. Important as this effect may be, it is not necessary to consider it in circuit calculations. Thus the value $\mu = 1.0$ is used in equations 1 and 3. It is stated in a later paragraph that

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the boosting effect previously noted may be given qualitative consideration with reference to the selection of frequency.

With the continuous-heating method for type-3 charges the effect of permeability on the rate of heat development is continuous but less in degree than in the batch heating of this type of charge. As with type-2 charges, the effective value of μ must be estimated or obtained by measurement.

Operating Index Ratio. The valve of the index ratio which corresponds to the values of specific resistance and permeability noted in the preceding paragraphs, to the given dimension a and to the selected frequency is termed the operating index ratio.

Current Values. Consider a charge of nonmagnetic material, and assume that the temperature of the charge is uniform throughout its mass. For that condition the value of the current in a core of the charge with radial thickness x measured from the vertical axis is given by the equation:

$$i_x = i_a\left(\frac{x}{a}\right)\left[\frac{\overline{\text{ber}}'^2\left(\frac{x}{\rho}\right)+\overline{\text{bei}}'^2\left(\frac{x}{\rho}\right)}{\overline{\text{ber}}'^2\,\Delta+\overline{\text{bei}}'^2\,\Delta}\right]^{1/2} \text{ amperes} \quad (4)$$

i_a = total current in the charge
a = radius of charge, centimeters

Volume V_p. The volume of the annular zone of the charge which is defined by the radial dimension ρ (the reference dimension), see Figure 2, per unit length is

$$V_p = \frac{\pi a^2}{\Delta}\left[2-\frac{1}{\Delta}\right] \text{ cubic centimeters} \quad (5)$$

Heat Development in Volume V_p. The value of the radial dimension x in equation 4 with reference to volume V_p is

$$x = (a-\rho) \quad (6)$$

Hence, in equation 4,

$$\frac{x}{a} = \left(\frac{a-\rho}{a}\right) = \left(1-\frac{1}{\Delta}\right) \quad (7)$$

and

$$\frac{x}{\rho} = \left(\frac{a-\rho}{\rho}\right) = (\Delta-1) \quad (8)$$

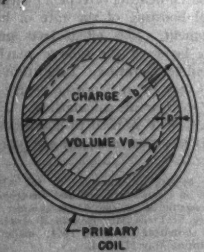

Figure 2. Relationship of the a, b, and ρ dimensions

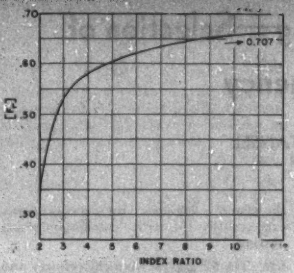

Figure 3. Values of the resistance function $|F_r|$ for solid cylindrical charges

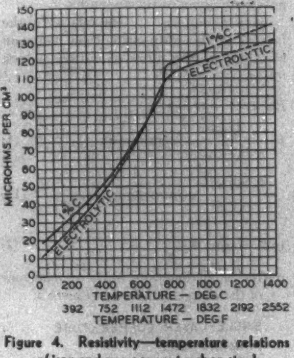

Figure 4. Resistivity—temperature relations of iron and one per cent carbon steel

If we substitute these values in equation 4,

$$i_{(a-\rho)} = i_a\left(1-\frac{1}{\Delta}\right)\times \left[\frac{\overline{\text{ber}}'^2(\Delta-1)+\overline{\text{bei}}'^2(\Delta-1)}{\overline{\text{ber}}'^2\,\Delta+\overline{\text{bei}}'^2\,\Delta}\right]^{1/2} \quad (4a)$$

For convenience write

$$i_{(a-\rho)} = g i_a \quad (4b)$$

The value of the current in the annular zone V_p is

$$i_p = (i_a - g i_a) = i_a(1-g) \text{ amperes} \quad (9)$$

The rate of heat development by eddy currents in volume V_p is thus

$$i_p^2 r_p = i_a^2 r_a - (g i_a)^2 r_a \text{ watts} \quad (10)$$

$$= i_a^2 r_a (1-g^2) \text{ watts} \quad (10a)$$

r_p = the resistance of the path of the current in annular zone V_p
r_a = the resistance of the path of the current in a core of the charge for any value of x up to and including $x = a$

The quantity $(1-g^2)$ in equation 10a is the fraction of the total heat development that is developed in volume V_p.

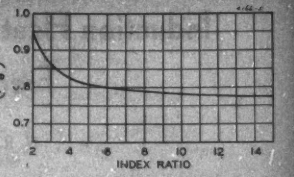

Figure 5. The fraction of the total heat development that is developed in volume V_p

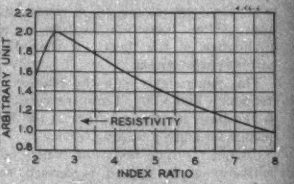

Figure 6. Resistance characteristic of the secondary circuit

Values of this fraction for a range of values of the index ratio are given in Figure 5.

The graph of Figure 5 depicts only the comparative concentrations of heat in the charge for the assumed uniform-temperature condition. The result of the temperature gradient in the mass of the charge during a heat cycle is to increase the concentration of heat development. With this in mind, the concept given by Figure 5 is useful in its indication of the manner in which heat development by eddy currents occurs in a charge.

The Electrical Problem. The factors μ and ρ and the dimension a in the preceding equations are given values for each application of induction heating. The electrical problem is the selection of frequency and the corresponding choice of the relation between volts and amperes for:

(a). The required rate of heat development.

(b). The desired concentration of heat represented by the graph of Figure 5.

This problem can be contrasted with the problem of minimizing the eddy-current loss in the magnetic structures of electrical machines. Here with given and constant values of frequency, permeability, and resistivity, the factor of selection is the dimension a: for example, one-half the thickness of a sheet for the core of a transformer.

Resistance Characteristic. If resistivity is taken as a variable and the only variable, in equation 26 for the resistance of the secondary circuit of the transformer of Figure 1 the resistance characteristic of that circuit, Figure 6, is obtained.

Electrical Efficiency. The electrical losses of induction heating are the i^2r loss

in the primary coil, see Figure 1, and some stray field loss. If iron is included in the outer portion of the magnetic circuit, the consequent core loss is added to the previously noted losses.

When the stray field loss and the core loss, if any, are neglected, the efficiency of the transformation is

$$\eta = \frac{r_a}{r_b + r_a} = \frac{r_a}{R} \tag{11}$$

r_a = the resistance of the secondary circuit
r_b = the resistance of the primary circuit

The resistance of the primary circuit, equation 23, is proportional to the square root of the frequency. The resistance of the secondary circuit, equation 26 is proportional to the product $[\sqrt{f}[F_r](Y)]$. If we consider frequency as a variable and start with a low value of the index ratio, the value of r_a increases faster than that of r_b and the efficiency of the transformation increase. This continues until with increasing frequency the product $[[F_r](Y)]$ becomes constant, see Figures 3 and 16. Thereafter, the efficiency is unaffected by increase of frequency. This characteristic is shown by curve *A* of Figure 7.

The one function of frequency in induction heating is to increase the resistance of the secondary circuit to obtain high efficiency of transformation. As the increase of efficiency by increase of frequency ends after a certain value of frequency is reached, there is no object in a higher frequency unless it may give a more desirable relation of volts and amperes or offer some economic advantage.

Power Factor. The power factor measured at the terminals of the primary coil of the transformer of Figure 1 is

$$\cos\varphi = \frac{R}{Z} \tag{12}$$

R = the total resistance, equation 28
Z = the corresponding impedance, equation 30

The power-factor characteristic corresponding to the efficiency characteristic of Figure 7 is shown by curve *B*, Figure 7.

Base Frequency. The characteristic of Figure 6 and the characteristics, *A* and *B* of Figure 7 indicate that the frequency for a given assembly should be a value that gives an operating index ratio not less than 2.50. Hence, the frequency which corresponds to the index-ratio value 2.50 is designated as the base frequency of an assembly for induction heating.

The equation for the base frequency is obtained by substituting $\Delta = 2.50$ in equation 2, thus:

$$f_B = \frac{79.0 \times 10^8 \times \rho}{a^2 \mu} \tag{13}$$

Example 1. $a = 3$ centimeters, $\rho = 114 \times 10^{-8}$ ohm-cubic centimeters, $\mu = 1.0$.

$$f_B = \frac{79 \times 114}{9} = 1{,}000 \text{ cycles}$$

Base Frequency and Index Ratio. Values of multiples of the base frequency and the corresponding values of the index ratio are given in Figure 8.

Example 2.

$f_B = 1{,}000$
$f_2 = 4{,}000$
$\Delta_2 = \sqrt{4} \times 2.50 = 5.0$

The graphs of Figure 9 show the base frequencies, $\Delta = 2.50$, and the frequencies which correspond to $\Delta = 3.50$ for a range of diameters of carbon steel at around 1,200 degrees centigrade.

Frequency and Current. The watts developed in a charge with the base frequency are

$$P_B = i_B^2 r_{aB} \tag{14}$$

and with some other frequency, f_2,

$$P_2 = i_2^2 r_{a2} \tag{15}$$

For the same rate of heat development in each case, that is, $P_2 = P_B$, the value of the current with frequency f_2 is

$$i_2 = i_B \left[\frac{r_{aB}}{r_{a2}}\right]^{1/2} \text{ amperes} \tag{16}$$

The symbol r_a with appropriate added subscript denotes the resistance of the circuit in the charge, equation 26 of the appendix.

A graph of Equation 16 with reference to the index ratio is shown in Figure 10.

Frequency and Voltage. The voltage measured at the terminals of the primary coil with a given watts input to the charge with the base frequency is

$$e_B = i_B Z_B \text{ volts} \tag{17}$$

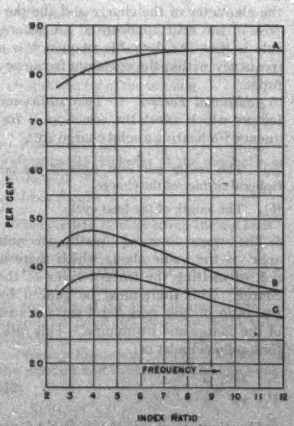

Figure 7

Efficiency–frequency characteristic, curve *A*
Power-factor–frequency characteristic, curve *B*
Curve *C*, the product of curves *A* and *B*

and with some other frequency, f_2,

$$e_2 = i_2 Z_2 \text{ volts} \tag{18}$$

For the same rate of heat development in the charge in each case, that is, $P_2 = P_B$, as before the voltage with frequency f_2, is

$$e_2 = e_B \left[\frac{r_{aB}}{r_{a2}}\right]^{1/2} \frac{Z_2}{Z_B} \text{ volts} \tag{19}$$

The symbol Z with appropriate subscript denotes the impedance of the circuit, equation 30 of the appendix.

Frequency and Kilovolt-Amperes. The product of equations 16 and 19 divided by 1,000 gives the relation,

$$\text{kva}_2 = \text{kva}_B \left[\frac{r_{aB}}{r_{a2}}\right] \frac{Z_2}{Z_B} \tag{20}$$

Example 3. Numerical values for the circuit equations are necessary to

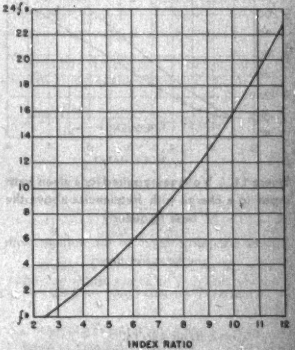

Figure 8. Values of multiples of the base frequency and corresponding values of the index ratio

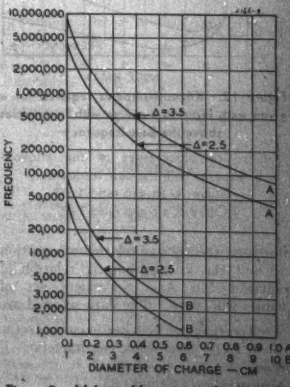

Figure 9. Values of frequencies for the index ratio values 2.50 and 3.50 for a range of diameters of carbon steel at 1,200 degrees centigrade

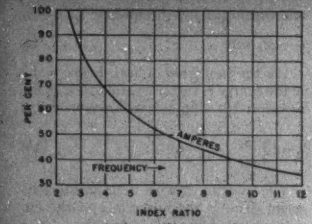

Figure 10. Values of current for a given watts input to a charge with frequencies above the base frequency

Values are percentages of the current with the base frequency

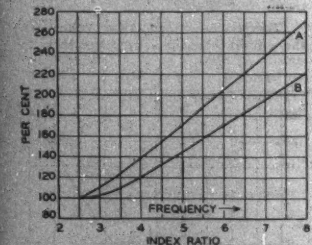

Figure 11. Voltages required for a given watts input to a charge with frequencies above the base frequency

Values are percentages of the voltage with the base frequency

Curve *A*, air-gap ratio, $\frac{b}{a}=1.20$

Curve *B*, air-gap ratio, $\frac{b}{a}=1.05$

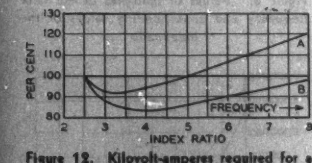

Figure 12. Kilovolt-amperes required for a given watts input to a charge with frequencies above the base frequency

Values are percentages of the kilovolt-amperes with the base frequency
Curve *A*, air-gap ratio 1.20
Curve *B*, air-gap ratio 1.05

illustrate the voltage relation of equation 19 and the kilovolt-ampere relation of equation 20. Any convenient set of values will serve. The data selected are

$a=3$ centimeters, $l=8$ centimeters, $\mu=1.0$,
$\rho=102\times10^{-6}$ ohm-cubic centimeters
$N=6$ $\quad s=0.81$
Air-gap ratios, 1.20 and 1.05

Voltage Relation. The voltages required for a given watts input to a given charge with different frequencies, up to ten times the base frequency, with the two air-gap ratios, are given in Figure 11 as percentages of the voltages required for the given watts input with the base frequency.

Kilovolt-Ampere Relation. The values of kilovolt-amperes required for the given watts input to a charge under the conditions noted for the voltage relation of the preceding paragraph are given in Figure 12.

Example 3, continued,

$\frac{b}{a}=1.20$, curves *A*, Figures 11 and 12,

Base frequency, f_B..... 900 cycles
New frequency, f_2.....8,100 cycles
New index ratio, Δ_2..... $\sqrt{9}\times2.60=7.50$
New current, i_2.....$0.46i_B$
New voltage, e_2.....$2.55e_B$
New kva$_2$.....1.17 kva$_B$

Frequency—Efficiency—Power Factor. The kilovolt-ampere relation of Figure 12 can be considered from the viewpoint of the product of efficiency and power factor, equations 11 and 12, respectively. The characteristic thus obtained is shown by curve *C* of Figure 7. This characteristic corresponds to curve *B* of Figure 12.

Optimum Frequency Range. The graphs of Figure 12 do not indicate a well-defined optimum frequency. There is an optimum range of frequency, and the smaller the air-gap ratio the wider is this range.

Service. The two divisions of induction-heating service are:

(*a*). Heating solids to temperatures below the melting points.

(*b*). Melting metals.

Heating Solids. The conditions of this service vary widely, both as regards the character of the charge and the purpose of the heat application. A general rule is that the desirable frequency is a frequency within the optimum frequency range.

Additional Factors. Two additional factors which affect the selection of frequency for heating a solid charge are:

(*a*). The watts per unit area of the peripheral surface of the charge.

(*b*). The length of the heat cycle.

The upper limit of "watts per unit area" is the value above which there is risk of melting the surface layer of the charge. This limit must be gauged by the ratio of the peripheral surface area of the charge and its volume. This ratio for a solid cylinder is

$$\frac{S_c}{V_c}=\frac{2\pi a}{\pi a^2}=\frac{2}{a} \qquad (21)$$

The limitations on the length of the heat cycle are:

(*a*). Grain growth.

(*b*). Surface oxidation.

The second limitation is a consequence of the "open-air" method of induction heating applied to solids.

A third factor not hereinbefore-mentioned is the depth of the hardened zone in the special application of heating steel for hardening.

The desirable depth of hardened zone in heating steel for hardening depends mainly on the type of steel and the service for which the part is intended.

These additional factors are matters of experience based on metallurgical considerations and cannot be embodied in general rules for practice. There is much useful information relating to these phases of induction heating in a paper by Vaughn, Farlow, and Meyer.[8]

It is often necessary to consider a range of diameters (thicknesses) of charges of a given material in the selection of frequency. The latitude of the optimum frequency range (if the air-gap ratio is taken into account) together with the degrees of freedom in the choice of "watts per unit area" and the length of heat cycle makes practicable the use of one frequency for a range of sizes of charges. Also, these conditions generally permit the use of a standard frequency in each case.

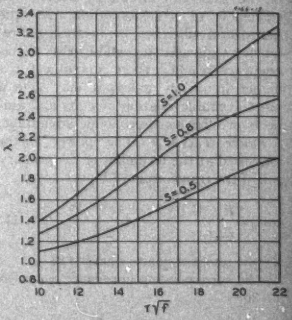

Figure 13. Values of λ for values of the product $r\sqrt{f}$

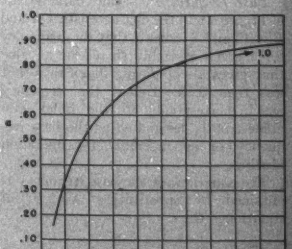

Figure 14. Values of α in equation 23

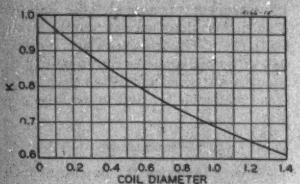

Figure 15. Values of K in equations 25 and 27

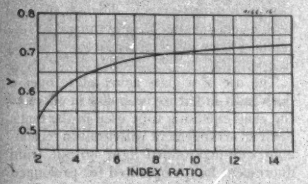

Figure 16. Values of Y in equation 26

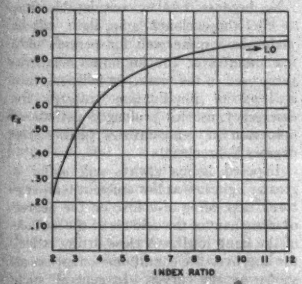

Figure 17. Values of the reactance function $[F_x]$ for solid cylindrical charges

Frequencies below the lower limit of the optimum frequency range are found in practice, particularly for type-3 charges. This practice gives qualitative consideration to the boosting effect of permeability as an aid in the initial rate of heat development. Also, frequencies above the upper limit of the optimum frequency range are in use. There is no technical objection to such frequencies where the practice is considered advantageous.

Melting Service. There are two special requirements which dictate the selection of frequency for metal-melting service. These are:

(*a*). The initial heating of a charge of scrap metal.

(*b*). The stirring of the molten metal by electrodynamic action.

Initially the index ratio is related to the nature of the charge and to the dimensions of the pieces of the charge. The frequency must be a value that gives a transformation efficiency high enough for effective initial heating, that is, to start the heat cycle.

After the charge has reached the liquid stage, the stirring of the metal by electrodynamic action is proportional to the square of the ampere turns. For a given watts input to the charge, the required ampere turns decrease with increase of frequency. The stirring of the liquid metal must be moderate in degree and the frequency must be suited to that requirement.

These two requirements and the economics of the service early led to the adoption in the United States of 960 cycles for steel-melting furnaces above 100-kva rating. The standard frequency for smaller furnaces is 3,000 cycles. Various higher frequencies are used for laboratory furnaces.

Appendix. Circuit Equations

The equations given herein are modifications of the theoretical equations of the circuits of the transformer of Figure 1. These equations were derived from experimental studies of circuits with frequencies up to 9,600 cycles and with charges with lengths not less than the diameters.

Primary Resistance. A single-layer coil with a water-cooled copper-conductor at 50 degrees centigrade is assumed.

The radial thickness of the conductor of this coil for the minimum a-c resistance of the coil is approximately

$$r = \frac{15}{\sqrt{f}} \text{ centimeters} \qquad (22)$$

The equation for the a-c resistance of the assumed coil is

$$r_b = [(r_b^0 - r_s)\alpha + r_s] \text{ ohm} \qquad (23)$$

$$r_b^0 = \frac{0.0018\sqrt{f}N^2b}{l\sqrt{s}\,10^9} \text{ ohm} \qquad (24)$$

f = frequency
N = number of turns
b = inside radius of coil, centimeters
l = length of coil, centimeters
s = space factor of the winding
$r_s = \frac{r_b^0}{\lambda}$
λ from Figure 13
r = the radial thickness of the conductor of the coil
α from Figure 14

This method of calculating the a-c resistance of a coil is based on the work of Burch and Davis.[1]

If the radial thickness of the conductor is less than the dimension given by equation 22, the value of the a-c resistance of the coil approaches more and more closely the value given by equation 24.

Primary Reactance. The reactance of the primary coil is calculated by the equation,

$$x_b = \frac{8\pi^2 f N^2 b^2}{l\,10^9}(K_b) \text{ ohm} \qquad (25)$$

K_b = correction for the proportion of the coil, Table X of circular 74, National Bureau of Standards.[5] Some of these values are given in Figure 15.

Effective Radius. As a rule with the frequencies used for induction heating the use of the inner radius of the coil in equations 24 and 25 as the effective radius of the path of current in the primary conductor is of sufficient accuracy.

Primary Capacitance. Generally, the capacitance of the primary coil can be neglected. It may be desirable to take it into account with very high frequencies.

Secondary Resistance. The a-c resistance of the circuit formed in the charge is calculated by the equation,

$$r_a = \frac{2\pi\rho N^2}{l}\Delta[F_r](Y) \text{ ohm} \qquad (26)$$

ρ = the resistivity, ohm-cubic centimeters, of the material of the charge at its maximum temperature
N = number of turns in the primary coil
l = length of charge, centimeters
Δ = the index ratio corresponding to the previously noted value of resistivity
$[F_r]$ from Figure 3
Y = a correction factor from Figure 16

Secondary Reactance. The equation for the reactance of the secondary circuit is

$$x_a = \frac{8\pi^2 f N^2 a^2}{l\,10^9}[F_x](K_a')(Y)^2/_3 \text{ ohm}$$

$$[F_x] = \left(1 - \frac{2\theta}{\Delta}\right),$$

$$\theta = \left[\frac{\text{ber}\,\Delta\,\text{bei}'\,\Delta - \text{bei}\,\Delta\,\text{ber}'\,\Delta}{\text{ber}^2\,\Delta + \text{bei}^2\,\Delta}\right] \qquad (27)$$

A graph of values of $[F_x]$ for a range of values of the index ratio is given in Figure 17.

K_a' = a correction from Figure 15 on the basis of the ratio,

$$\frac{2a\left(1 - \frac{0.50}{\Delta}\right)}{l}$$

Combined circuit, primary and secondary:

Resistance, $R = (r_b + r_a)$ ohm (28)

Reactance, $X = (x_b - x_a)$ ohm (29)

Impedance, $Z = (R^2 + X^2)^{\frac{1}{2}}$ ohm (30)

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Gaseous-Discharge Lamps for Airplane Lighting Service

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FLUORESCENT lamps always have been considered desirable for general lighting within the airplane in order to reduce power consumption and utilize the long thin tubular-light sources that fit in so well in the interior of an airplane. Four-hundred-cycle operation has been found by Hays[1,2] to be excellent for fluorescent lamps, providing about 20 per cent greater efficiency than the 60-cycle alternating current for which these lamps were created originally and reducing the size and weight of the ballasts required. However, uncertainty as to lamp operation at low temperatures and particularly at the extremes of low temperature that might be encountered at tremendous altitudes has prevented the general use of these lamps in this field.

The fact that fluorescent lamps now are used for instrument lighting in military airplanes has indicated that the danger of starting and operating trouble is small, but, since these instrument lamps are enclosed within heat-conserving housings, it has been thought that the good performance they give may not be sufficient proof that larger fluorescent lamps will give equally good service in cabin lighting and other similar uses.

Similarly, while glow lamps now are used successfully in certain special applications in airplane lighting and for indicator service, very little has been recorded regarding their performance on the 400-cycle alternating current commonly used in airplanes. Consequently, a study was made of the effect of low-temperature and 400-cycle operation on these two types of lamps in order, if possible, to release them for general use in airplane service.

Fluorescent Lamps

The chief problem with the fluorescent lamp is to determine its performance throughout the normal anticipated range of ambient temperatures and also to carry this investigation down to the extremes of low temperature that might be encountered at high altitudes. In this low-temperature investigation the assumption was made that, in certain emergencies which might occur during the war, the interior of the airplane might reach the same temperature as the outside air. Such a condition probably would occur rarely if ever in civilian operation, but the information always would be of value in determining the practical as well as the theoretical range of usefulness for this type of lamp.

In this investigation standard 15-watt T-8 bulb lamps were tested in three representative types of installations. One consisted of the bare lamp exposed to natural flow of the surrounding air. The second consisted of the lamp with a fairly close-fitting reflector designed to conserve some of the heat generated by the lamp. The third consisted of a lamp surrounded by a glass tube sealed at each end so as to minimize the heat loss from the lamp when operated at low temperatures. These lamps were operated at both 400 and 60 cycles for comparison.

The lamps were placed in the cold box and brought to full equilibrium at various temperature points. Where small temperature changes caused large changes in lamp performance the time required to reach a steady state ranged up to an hour. Readings were made of voltage, amperage, and relative light output. Starting characteristics were checked throughout the temperature range. All values reported represent the average of several lamp runs, so that the values indicate quite closely what would be obtained in service.

The lamps were operated at normal wattage. At 400 cycles this required operation at a current of 0.400 ampere at which the lamps generate approximately 120 per cent of normal light output. This higher than normal current overloads the electrodes somewhat. Operation at normal amperes corresponding to about 13 watts and normal lumens may be found preferable for civilian use after the war.

Light Output

The tests revealed the important fact that this 15-watt T-8 lamp will stay lighted down to the extremely low temperatures encountered at high altitudes on either 60 or 400-cycle current. At the higher frequency they show a slightly better maintenance of light output at low temperatures and a larger factor of safety in operation.

The use of a glass cover plate over a flush built-in fixture is similar in effect to the glass enclosing tube used in the tests. Such an arrangement will result in reasonably well-maintained light output from fluorescent lamps operated for prolonged periods of time at ambient temperatures well below zero degrees Fahrenheit. Also, because it takes considerable time to cool the enclosed lamp, light will be maintained quite well for periods of a few minutes at the minimum temperatures used in the tests. It will maintain a level of illumination suitable for emergency use for prolonged periods of operation at temperatures below −50 degrees Fahrenheit.

Exposed lamps always will suffer a greater light loss at low ambient temperatures, depending of course on the degree of movement of the cold air at the surface of the lamp itself. A close-fitting reflector improves the conditions somewhat as shown by the curves. In general, such an arrangement of the reflector to conserve heat is well worth while and is recommended lighting practice to reduce glare.

Lamp Operation

Low-Temperature Starting. Fluorescent lamps are designed to be started by means of a starting switch of some sort. This may be a simple manual switch or an automatic device such as the standard glow switch or the thermal switch, which

Figure 1. Test lamps were mounted on open wooden rack to test effect of cold surrounding air on lamp performance

Front lamp bare; middle lamp protected by glass-tube jacket; rear lamp operated beneath close-fitting reflector, reflector turned back to show mounting

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E. W. Beggs is in the Westinghouse lamp division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

The author acknowledges experimental work done by V. H. Laughner, K. F. Melton, and A. J. Dupault.

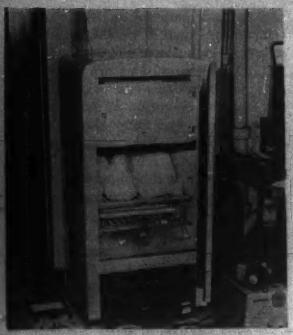


Figure 2. Lamp rack installed in cold box

Door opened to show test setup. Equilibrium reached for each reading, requiring in some cases a period of two hours

Figure 3. All lamp characteristics measured by meters outside cold box

Photoelectric cell and thermocouple inside chamber measured relative light output and ambient temperature at the lamp

is frequently used under adverse starting conditions such as at low temperatures. Various standard methods and modified schemes of starting were tested to determine starting reliability over the test range of temperature.

Lamp starting is critically affected by line surges, by capacitative effect of metal such as reflectors located adjacent to the lamp bulb, and by static effects in the air particularly as influenced by humidity. Not all possible combinations of circumstances were explored, and so this report on starting is merely a record of experiments run. It is probable, however, that in ordinary operating conditions the results will be about the same as found in these tests.

Starting of fluorescent lamps with the standard glow switch on 118-volt 60-cycle lines generally becomes somewhat undependable below 40 degrees Fahrenheit. Four-hundred-cycle operation is somewhat more favorable for starting, but good practice is to recommend glow-switch starters for temperature ranges down to 50 degrees Fahrenheit. The circuit is generally familiar and is shown in Figure 4. Below this point other starters should be used on both 60 and 400 cycles.

On 60-cycle circuits low-temperature conditions require the use of a thermal starter. This greatly improves starting and eliminates practically all danger of recycling of the starter. With such starters on 60 cycles standard 15-watt lamps and equipment are dependable down to zero degrees Fahrenheit. On 400 cycles, however, the thermal starter alone is not appreciably more effective than the glow switch, so other methods of starting are required for dependable starting at low temperatures.

For low-temperature operating conditions on 400 cycles a small series capacitor provides dependable starting with either the manual or the automatic thermal starter. Such a device is shown in the diagram in Figure 5. For the 15-watt T-8 lamp tested, a capacitor of one microfarad starts the lamp readily down to about −10 degrees Fahrenheit. A capacitor of $1^1/_2$ microfarad starts it down below −30 degrees Fahrenheit.

The use of the series capacitor for starting is highly effective for 400-cycle operation, but if the lamps are turned on and off frequently it tends to shorten lamp life and so is recommended only if assurance of dependable lamp starting at low temperatures is more important than long lamp life. Normal life on standard circuits at normal amperes (0.30 *A*) is 2,500 hours with the lamp turned on and off once for each three hours of burning. Using the $1^1/_2$-microfarad capacitor described previously and operating the lamps at 0.40 ampere, it is probable that lamp life will be reduced to an average of approximately 1,000 burning hours. Where a longer lamp life is desired the lamps may be operated at lower wattage.

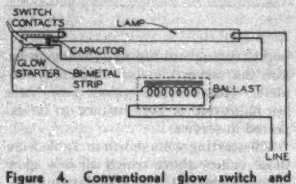


Figure 4. Conventional glow switch and choke circuit for fluorescent lamps suitable for 60 or 400 cycles

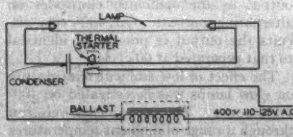
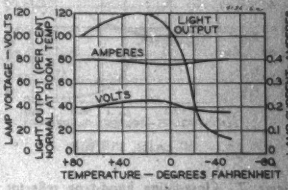


Figure 5. Special 400-cycle circuit to provide dependable starting of fluorescent lamps at low temperatures

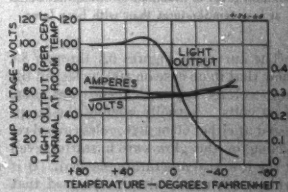
Steadiness and Recycling of Starters

No evidence of unsteady operation was noted during these tests. The light meter cell was inside the chamber and showed no minor fluctuations of light output. The voltmeter and ammeter also gave good indication of steady operation throughout the entire temperature range. In addition the door often was opened for a moment to observe conditions, and in no instance did unsteady operation show up.

Recycling of the standard glow-switch starter at low temperatures results when the cold raises the lamp arc voltage to a value equal to or above the breakdown voltage of the gas (neon or argon) in the glow switch itself. This causes the lamp to flash alternately on and off. The 15-watt T-8 lamp has a normal 60-cycle



A. 400 cycles, 118 volts

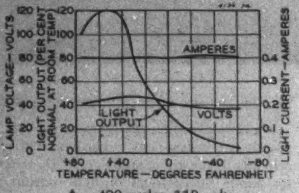


B. 60 cycles, 118 volts

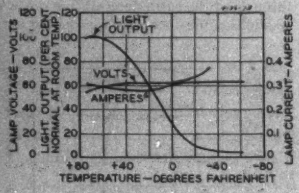
Figure 6. An enclosed fluorescent lamp maintains its light output at low temperatures, particularly on 400-cycle circuits

Tests run with clear glass cylinder around lamp as shown in Figure 1. Still air throughout all tests

voltage of 56 volts, while at 400 cycles the voltage is only 43 volts. The minimum breakdown voltage of the neon filling gas with the electrodes used in the standard *FS-2* starter switches is 80 volts at 60 cycles and somewhat higher at 400 cycles. These breakdown volts are practically unchanged at any ambient temperatures that may be encountered. This provides a wide factor of safety with glow-switch starters in 400-cycle operation.



A. 400 cycles, 118 volts



B. 60 cycles, 118 volts

Figure 7. Close-fitting hood-type reflector above lamp tends to conserve lamp heat and maintain level of illumination somewhat better at low temperatures than with bare lamp

The curves in Figures 6A through 8A show that in no case on 400 cycles did the lamp voltage approach the critical value of 80 volts. Actually none of the lamps tested at either 60 or 400 cycles caused recycling of the glow-switch starter even at the lowest temperature reached. It is evident from the voltages obtained that there will be no danger with this size lamp of recycling in service, and it may be that on 400 cycles larger lamps, such as the 20-watt *T*-12 size can be operated without recycling at lower temperatures than on 60-cycle circuits.

Glow Lamps

Glow lamps are particularly well suited to 118-volt a-c airplane indicator service, because they consume very little power and are extremely rugged even in the small sizes generally used for indicator lights. Consequently, investigations were made to determine the effect of 400-cycle power on lamp operation and also the effect of low ambient temperatures on the lamp performance. Table I shows the starting volts above which dependable starting will be obtained for direct current, 60-cycle, and 400-cycle alternating current for several types of glow lamps suggested for airplane indicator service.

These values reported in Table I were obtained from several samples of each of the lamp types shown. Because of the inherent variation of the glow lamp, many more samplings and readings at various

Table I

Lamp Type	Catalog No.	Approximate Starting Volts D-C	60 Cycles	400 Cycles
1/4 watt, *T*-4 1/2, candelabra, screw, neon	*NE*-45	90	65	76
1/3 watt, *G*-10, medium, screw, neon	*NE*-27	—	105	135
1 watt, *G*-10, medium, screw, neon	*NE*-30	85	60	69
2 watts, *S*-14, medium, screw, neon	*NE*-34	85	60	73

points throughout life must be made before the survey can be considered complete. However, the values given here are indicative of performance to be expected in service.

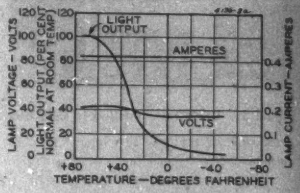
The starting volts shown in Table I are those values above which all new glow lamps should start. Individuals frequently start at lower voltages. On direct current only one electrode (negative) glows, producing approximately the same light output as the combined electrodes on alternating current. On 400-cycle circuits the output is practically identical to that generated at 60 cycles.

The effect of low ambient temperature on glow lamps was investigated on 400-cycle power. The experiments were run through a range of ambient temperatures from 70 degrees Fahrenheit down to −60 degrees Fahrenheit. Throughout this range the change in the light output and the operating characteristics of these glow lamps was negligible, even though the lamps were not enclosed but were exposed to the air.

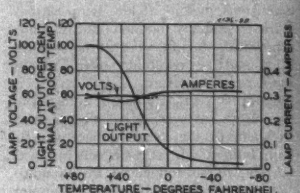
Conclusions

Fluorescent Lamps

It is evident from the experiments run that satisfactory light output, high efficiency of light production, and dependable operation of fluorescent lamps are readily obtainable on 400-cycle airplane circuits. Ordinary equipment with special lightweight efficient 400-cycle chokes is adequate for ordinary ranges of temperature such as will be encountered in areas which people will occupy in comfort. Where provisions are to be made for emergencies or where military necessity involves operation at lower ambient temperatures, the lamp should be enclosed to maintain light output, and manual or thermal starter switches with a small series capacitor should be used to provide dependable starting.



A. 400 cycles, 118 volts



B. 60 cycles, 118 volts

Figure 8. Simple mounting of bare lamp is satisfactory for normal ambient temperatures, although shielding of light from view of passengers is desirable to eliminate glare

Lower lamp volts on 400 cycles shown in curves eliminates all danger of recycling of glow switch at extremely low temperature ranges

Glow Lamps

Glow lamps are practically unaffected by low ambient temperatures, and their performance is excellent at 400 cycles. These small rugged low-wattage long-lived light sources are recommended particularly as indicator lights on circuits of relatively high voltage such as on the 118-volt a-c lighting systems of new large-sized airplanes. In that application they will provide a maximum of dependability with a minimum of power consumption.

References

1. Characteristics of Low-Voltage Fluorescent Lamps at High Frequencies, R. F. Hays. *Illuminating Engineering*, May 1941.

2. High Frequency Adapts Fluorescent Lamps to Aircraft, R. F. Hays. Electrical Engineering, volume 60, November 1941, page 539.

Hot-Spot Temperatures in Dry-Type Transformer Windings

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MEMBER AIEE

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Synopsis: With the increasing use of dry-type transformers, attention has been focused upon the fact that the difference between the average temperature rise by resistance and the hottest-spot temperature rise is much greater than in liquid-immersed transformers.

In this paper there are given the results of an extended series of thermal tests on a variety of dry-type transformer coils. Data are presented in regard to the effect of different heights of coil stacks, different configurations, and, in addition, some essential precautions in making temperature measurements are pointed out. Hot-spot temperatures were investigated in coils cooled by natural draft and by forced-air circulation at different velocities for both directed flow and random flow.

Sufficient data are given to determine the ratio between the average temperature rise of the windings and the hottest-spot temperature rise. Based upon this relationship, the need is shown for review and modification of the conventional hot-spot allowances for dry-type transformers.

IN the last few years there have been major advances in the manufacture and availability of class *B* insulating materials, together with improvements in the design of structures using these materials.

This has made possible a large increase in the upper limit of voltage and output ratings of dry-type transformers. A wider range of applications is now possible and correspondingly, an increasingly great volume of these units is being built. These transformers are no longer special cases but should be regarded as an important class of transformers meriting serious and careful attention to their special problems and limitations, as well as attention to their possible advantages.

Previous to these developments, dry-type transformers were cooled by the conduction of heat through solid insulation to the enclosing case or were for the most part sufficiently small so that adequate cooling was easily obtained. With the advent of higher voltages and larger output ratings, satisfactory cooling becomes a major problem and unless such transformers are conservatively designed, winding hot-spot temperatures will exceed established standards. Excessive hot-spot temperatures will, of course, hasten the deterioration of the insulation and shorten the life expectancy of the transformer.

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The authors acknowledge the technical advice relative to the measurement of temperatures received from V. M. Montsinger and A. U. Welch of the power transformer division of the General Electric Company, Pittsfield, Mass.

Present Hot-Spot-Temperature Standards

At the present time, American Standards for Transformers[1] specifies a 55-degree-centigrade average temperature rise by resistance and a 10-degree-centigrade hot-spot allowance for transformers with class *A* insulation. These same standards give a limit of 80 degrees centigrade rise by resistance of transformer windings with class *B* insulation but no limit is given for either hot-spot increment or for hot-spot temperature rise. Data in this paper will show that the hot-spot increment for average temperature rises of 55 degrees centigrade and 80 degrees centigrade for dry-type air-cooled transformers using class *A* and class *B* insulations respectively will greatly exceed 10 degrees centigrade for the commonly used arrangements of windings.

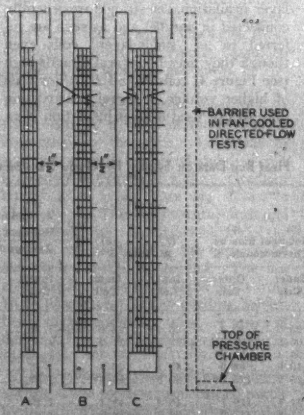

Figure 1. Typical arrangement of coils for tests, showing barrel coils with thermocouple locations

Temperature Measurement of Bodies in Air

It is necessary to take many precautions in the measurement of hot spots in windings cooled by air. First, it is highly desirable to insert measuring means into the winding itself. Measurement of the surface of the winding leads to inaccuracies since the radial gradient of these windings may be considerable, particularly when forced-draft cooling is used. Also, it is not clear whether it is the coil surface temperature or whether it is the temperature of the air film at the surface that is being measured. Coverings on the thermometer or thermocouple bulb reduce but do not eliminate this uncertainty. All measurements of winding hot spots as described in this paper were made by thermocouples buried in the winding and secured in place at the time of winding. Only turn insulation plus a very thin layer of asbestos separated the thermocouple from the copper of the winding in all cases. This totaled from 12 to 15 mils. When a thermocouple is in the maximum temperature level where there is no transfer of heat, the adjacent copper temperature is, of course, reached.

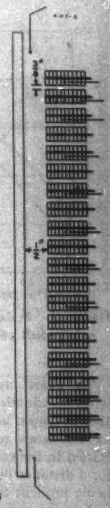

Figure 2. Disk coil showing thermocouple locations

All windings used in these tests were wound noninductively. This reduced the voltages required to approximately the *IR* drop of the conductors, permitted the use of alternating currents, and allowed thermocouple measurements to be made continuously while power was on without the necessity of taking cooling curves to correct back to shutdown for determining hot spots.

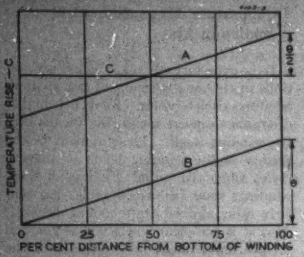

Figure 3. Previously proposed but incorrect axial winding and air gradients

A—Winding temperature rise by thermocouple
B—Air-duct temperature rise by thermocouple
C—Average winding temperature rise by resistance

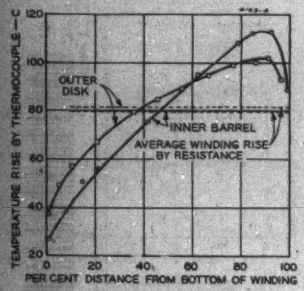

Figure 4. Axial winding gradients with natural-draft cooling for 30½-inch coils

To guard against the thermocouple wires conducting heat to or from the thermocouple bead and hence indicating an erroneous reading, these wires were buried in the coil in an isothermal region for a distance of at least six inches before being brought to the coil surface.

Average temperatures of the windings were determined by resistance measurements with cooling curves taken to correct temperature back to shutdown.

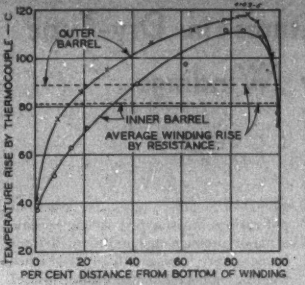

Figure 5. Axial winding gradients with fan cooling for 30½-inch barrel coils

In the case of air-temperature measurements, thermometer or thermocouple in an air stream will measure the temperature of the air only if it is protected from receiving or giving up heat due to radiation to or from other bodies. A silvered tube one inch long and three-eighths inch in diameter was used around the thermocouple bead in these tests with the bead held in a central position by means of cross threads. This allowed the air stream to contact the thermocouple but shielded it from receiving or losing much heat by radiation. In the configurations tested, an unshielded thermocouple indicated air temperatures several degrees in error.

Types of Windings

Two general types of coils are used in air-cooled dry-type transformers. The first type is coils having vertical ducts only which are hereafter referred to as "barrel" coils. They may be wound with or without layer insulation. Without layer insulation, the strands are generally connected in parallel and as such are referred to as "single-layer" coils even though they may be several strands high (see Figure 1, coils *A* and *B*). For coils of higher voltage, a barrel construction may still be used if layer insulation is introduced between layers. Such a coil is hereafter referred to as a "multilayer" coil (see Figure 1, coil *C*).

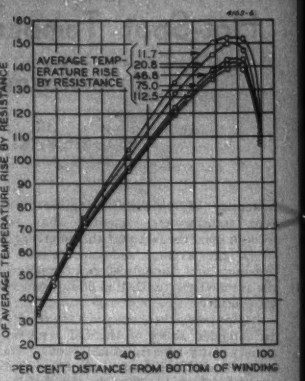

Figure 6. Axial winding gradients at various loads with natural-draft cooling for 30½-inch barrel coils

A second type of coil has an arrangement of horizontal ducts, as well as a vertical duct. These coils are hereafter referred to as "disk" coils (see Figure 2). Such coils are generally used as outside coils only as they usually have poor cooling efficiency if used as inside coils in dry-type transformers.

Types of Coils Tested

Barrel coils were tested in heights of 12½, 30½, and 60½ inches, actual winding lengths, and disk coils in 30½-inch stack height only. These coil heights are typical of dry-type transformers in ratings of 25 to 3,000 kva inclusive.

Ducts were in general one-half inch wide for vertical ducts and three-eighths inch for horizontal.

Arrangement of Coils

Coils were arranged as in Figure 1 for these tests. This arrangement has an in-

Table I. Heat Run Data on Typical Dry-Type Transformer Coils

(1) Winding Height, In.	(2) Air Velocity, Ft Per Min	(3) Average Rise by Resistance, C		(5) Hot-Spot Rise by Thermocouple, C		(7) Air Rise, C		(9) Ratio: Hot-Spot Rise / Average Rise		(11) Hot-Spot Increment, C		(13) Ratio: Hot-Spot Increment / Air Rise	
		Inner Coil	Outer Coil	Inner Coil	Outer Coil	Inner Coil	Outer Coil	Inner Coil	Outer Coil	Inner Coil	Outer Coil	Inner Coil	Outer Coil
12½	†	72.9	70.3	95.0	83.4	53.1	26.0	1.30	1.19	23.1	13.1	0.415	0.50
30½	†	76.0	72.7	106.8	94.3	72.7	21.0	1.40	1.30	30.8	21.6	0.432	1.03
30½	†	74.5	74.3*	104.4	90.3*	77.3	57.3*	1.40	1.21*	29.9	16.0*	0.387	0.28*
60½	†	74.5	74.0	110.6	99.9	83.1	20.4	1.48	1.35	36.1	25.9	0.433	1.27
30½	**	82.6	84.4*	125.2	125.2*	59.8	56.7*	1.52	1.49*	42.6	40.8*	0.713	0.72*
30½	530	86.0	86.4	121.7	119.7	46.3	13.4	1.42	1.39	35.7	33.3	0.77	2.48
30½	2,015	81.2	89.3	111.3	118.3	28.2	22.1	1.37	1.33	30.1	29.0	1.07	1.31
60½	490	69.2	67.7	106.2	101.1	55.9	23.5	1.56	1.49	38.0	33.4	0.680	1.42
60½	1,610	80.4	81.9	120.8	117.9	58.1	20.4	1.50	1.44	40.4	36.0	0.695	1.76

† Natural draft. * Disk-type winding similar to Figure 2. ** External 12-inch fans. Velocity in inner ducts 450 feet per minute.

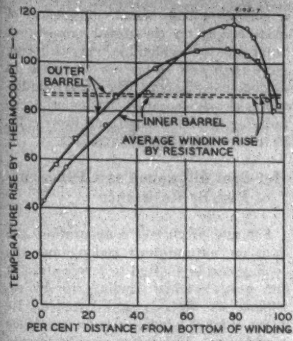
TEMPERATURE RISE BY THERMOCOUPLE—C
OUTER BARREL
INNER BARREL
AVERAGE WINDING RISE BY RESISTANCE
PER CENT DISTANCE FROM BOTTOM OF WINDING

Figure 7. Axial winding gradients with natural-draft cooling for 12½-inch barrel coils

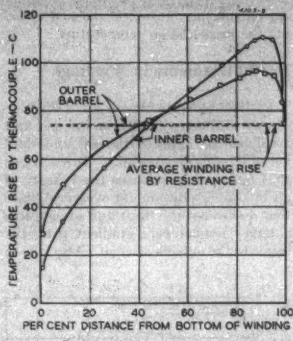
TEMPERATURE RISE BY THERMOCOUPLE—C
OUTER BARREL
INNER BARREL
AVERAGE WINDING RISE BY RESISTANCE
PER CENT DISTANCE FROM BOTTOM OF WINDING

Figure 8. Axial winding gradients with natural-draft cooling for 60½-inch barrel coils

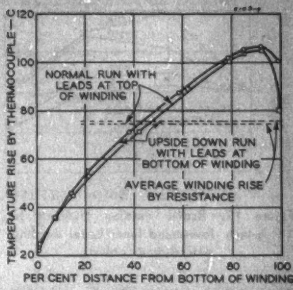
TEMPERATURE RISE BY THERMOCOUPLE—C
NORMAL RUN WITH LEADS AT TOP OF WINDING
UPSIDE DOWN RUN WITH LEADS AT BOTTOM OF WINDING
AVERAGE WINDING RISE BY RESISTANCE
PER CENT DISTANCE FROM BOTTOM OF WINDING

Figure 9. Axial winding gradients with natural-draft cooling showing effect of leads

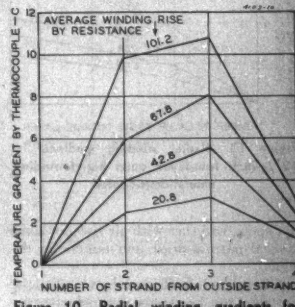

Figure 10. Radial winding gradients for 60½-inch four-strand inner barrel winding, fan-cooled

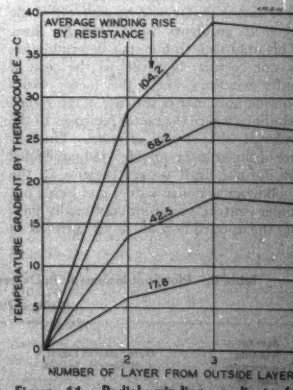

Figure 11. Radial winding gradients for 60½-inch four-layer outer barrel winding, fan-cooled

ner coil *A* which provided the heat that would normally be supplied by a core or an adjacent winding. No core iron was used but a core and yokes of wood were built into each test setup which approximated the air restrictions which would exist in an actual transformer. Windings *A* and *B* were connected in series so that their average temperature rise was within about five per cent of each other. A tap was provided between windings *A* and *B* so that average temperature rise by resistance of each could be determined.

Since the coils were wound noninductively, the currents in windings *A*–*B* could be adjusted independently of that in winding *C*. In well-designed transformers, the temperature rises of all windings should be approximately equal; therefore, in these tests the currents in all windings were adjusted to give approximately this result.

Types of Cooling

In the smaller sizes, dry-type transformers are usually cooled by natural-draft air circulation. In the larger sizes, fan cooling of some form can be efficiently used. Fan cooling can be generally divided into two types, the so-called directed flow and random flow.

In the directed-flow type of cooling, a motor-driven fan builds up a static pressure in a compartment whose only outlets are through the cooling ducts of the coils and core. Hence, there is a definite and controllable pressure drop across these cooling ducts and consequently a definite and controllable velocity of air flow in all these ducts. If these cooling ducts are designed so as to have equal frictional entrance and exit losses, the air velocities in these ducts will be equal. In practice it may be desirable to design these ducts to have somewhat different air velocities so as to cool some parts of the coils more than others due to differences in loss per unit area of the surfaces. It is thus evident that this method of fan cooling permits accurate design and prediction of winding temperatures. In the test setup an additional cylinder was placed around the outer coil to direct the air flow past this coil and so obtain directed flow.

The random-flow type of cooling utilizes fans blowing air freely against the transformer core and coils. The air streams in this case are directed only by the location of the fans with relation to the windings. Considerable care and a trial-and-error method is necessary to give maximum efficiency to such an arrangement.

Axial Gradients in Windings

It might seem reasonable to assume that the axial gradient in these air-cooled coils would be a straight line whose maximum value at the top of the winding would be the average rise by resistance of the winding plus one half of the temperature rise of the air which flows past these windings. Such incorrectly assumed gradients and relations are shown in Figure 3.

Actual gradients were measured in these tests by a series of thermocouples embedded in the coils. Locations of thermocouples in the barrel and disk coils are shown in Figures 1 and 2. Gradient curves from actual data are shown in Figures 4 and 5 for both natural-draft and fan-cooled units. A marked feature of the vertical coil gradients is the turnover of the curves at the upper end. The hot spot was found to be at some point from 75 to 95 per cent of the winding height, being higher for taller coils. A series of curves taken at various loads is shown in Figure 6.

This turnover at the upper end is due to cooling of the top few turns caused partly by radiation and convection at the end of the coil, but primarily by conduction of heat away by the foundation cylinders and the coil leads. The effect of the leads is strikingly shown by inverting a coil so that leads are alternately at the top and the bottom. The change in the gradients in these two cases is shown in Figure 9.

Table I gives some of the test data on

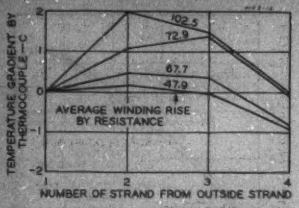

Figure 12. Radial winding gradients for 12½-inch four-strand inner barrel winding, natural-draft-cooled

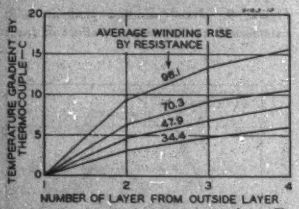

Figure 13. Radial winding gradients for 12½-inch four-layer outer barrel winding, natural-draft-cooled

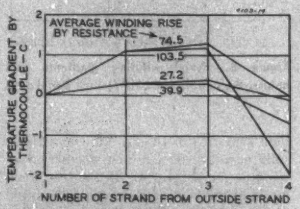

Figure 14. Radial winding gradients for 60½-inch four-strand inner barrel winding, natural-draft-cooled

hot spots, together with air rises for some typical natural-draft and fan-cooled designs.

For natural-draft inner-barrel coils, the hot spot can be closely approximated by adding 40 per cent of the temperature rise of the air flowing past these coils to the average temperature rise by resistance of the coil. This compares with the 50 per cent factor that would be expected if the vertical gradients were straight lines. This approach to hot-spot determination is not correct, however, in the case of outer windings where this factor varies considerably, nor in the case of fan-cooled windings where the factor increases to the order of 100 per cent or more. The failure of this rule for outside windings cooled by natural draft occurs because all the cooling air is not in a duct and hence not under control, cooler air continually joining the upward flow of the air currents on the outside face of the coil and so decreasing the measured air temperature.

Radial Gradients in Windings

Radial gradients in coils are a function of turn and layer insulation, loss per unit area, velocity of air by the coil, and number of strands high radially. It is obvious that fan cooling increases the velocity of air by the coils by a factor of several times that due to natural draft and so produces a larger temperature gradient from the inside to the outside of a coil. Also, due to the over-all cooling effect, the loss per unit area of such coils can be raised by a considerable factor without exceeding guaranteed rises. This totals to a considerable radial gradient in the case of fan-cooled units. Typical radial gradients for fan-cooled units are shown in Figures 10 and 11. In all cases the radial gradients shown are taken at or near the height that the maximum axial temperature occurs.

The radial gradients of inner coils are considerably greater in the case of fan cooling as compared with natural-draft cooling. The contrast in the case of outer coils is somewhat less since the radial gradient is already quite large due to loss of heat by the coil through radiation and also its contact with cool ambient air.

The radial gradients of inner coils cooled by natural draft are small and the effect of axial height on the radial gradient is correspondingly small. The effect of axial height on the radial gradient of outer coils is considerable, however, being more than two to one for the range of heights investigated. The effect of radiation is clearly shown when comparing the radial gradients of outer and inner coils, as for example Figures 10 and 11.

Hot-Spot Allowance as a Function of Rise by Resistance

For any given coil configuration, the data for natural-draft cooling and fan cooling can be plotted to give a straight line using average winding rise by resistance as abscissa and hot-spot rise minus average winding rise by resistance as ordinate. This latter may be termed the "hot-spot increment"; hence, from geometry,

$$Y = m X$$

where

Y = hot-spot increment
X = average winding rise by resistance

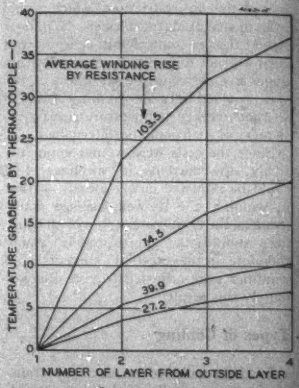

Figure 15. Radial winding gradients for 60½-inch four-layer outer barrel winding, natural-draft-cooled

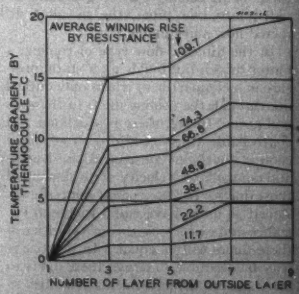

Figure 16. Radial winding gradients for 30½-inch ten-layer outer disk-type winding, natural-draft-cooled

Table II. Hot-Spot Increments in Degrees Centigrade for Dry-Type Transformers

Natural-Draft-Cooled

Average Winding Temperature Rise by Resistance, C	Outer Barrel Coils; Coil Height, Inches			Inner Barrel Coils; Coil Height, Inches			Outer Disk Coils; 30½ In. Height, 1 In. Build
	12½	30½	60½	12½	30½	60½	
45	9.5	12.5	18.5	16.5	19.5	21.5	10.5
50	10.5	14.0	20.5	18.0	21.5	24.0	11.5
55	11.5	15.5	22.5	19.0	23.0	26.5	12.5
60	12.5	17.0	24.5	20.5	25.0	29.0	13.5
65	13.5	18.5	26.5	21.5	27.0	31.5	14.5
70	14.5	20.0	29.0	22.5	29.0	34.0	15.5
75	15.5	21.5	31.0	24.0	30.5	36.5	16.5
80	16.5	23.0	33.0	25.0	32.5	39.0	17.5
90	19.0	25.5	37.0	27.5	36.0	43.5	19.5
100	21.0	28.5	41.0	30.0	40.0	48.0	21.5

Table III. Hot-Spot Increments in Degrees Centigrade for Dry-Type Transformers

Fan-Cooled

Average Winding Temperature Rise by Resistance, C	Air Velocity, Ft Per Min	Outer Barrel Coils; Coil Height, Inches				Inner Barrel Coils; Coil Height, Inches				Outer Disk Coils; $30^1/_2$ In. Height, 1 In. Build
		$30^1/_2$		$60^1/_2$		$30^1/_2$		$60^1/_2$		
		530	2,015	490	1,515	530	2,015	490	1,515	450
45		16.5	15.5	22.0	21.0	20.0	18.5	25.5	23.0	23.0
50		18.5	17.0	24.5	23.0	22.0	20.0	28.5	25.0	25.5
55		20.5	18.5	27.0	25.5	23.5	22.0	31.5	27.5	28.0
60		22.5	20.0	30.0	27.5	25.5	24.0	34.5	30.0	30.5
65		24.5	21.5	32.5	29.5	27.5	25.5	37.5	32.5	33.0
70		26.5	23.0	35.0	32.0	29.5	27.5	40.5	35.0	35.5
75		28.5	24.5	37.5	34.0	31.5	29.0	43.5	37.5	37.5
80		30.5	25.0	40.0	36.0	33.5	31.0	46.5	40.0	40.5
90		34.5	29.0	45.5	40.5	37.0	34.5	52.5	44.5	45.5
100		38.5	32.0	50.5	45.0	41.0	38.0	58.5	49.5	50.0

$m = 0.21$ to 0.58 depending upon coil configuration (slope of the line)

This same relation may also be expressed as a ratio of hot-spot temperature rise by thermocouple to average rise by resistance as shown in columns 9 and 10 of Table I.

The coil height is a considerable factor in the hot-spot increment. This is true for both inner and outer coils.

These data can be further correlated into bands by noticing that outer coils cooled by natural draft fall into a lower band than inner coils cooled by natural draft (see Figure 20). While these bands are quite wide, it should be noted that test data cover coils of widely differing heights and layer insulation, as well as different types. Disk coils of rather small build and of medium height (approximately one-inch build and $30^1/_2$-inch stack height) were used and this undoubtedly accounts for their being near the lower side of the band (lower curve in Figure 19). It is to be noted that there is about a five-degree-centigrade difference in the hot-spot increment between inner and outer coils in the ordinary range of temperature rises. This is explained by the loss of heat throughout the height of the coil by the radiation component.

Fan-cooled coils were tested in heights of $30^1/_2$ inches and $60^1/_2$ inches only, since at the present time it is believed to be economically feasible to build only the larger kilovolt-ampere sizes of dry-type transformers fan cooled. It is to be expected that there is only a small difference in the hot spots of inner and outer coils cooled by forced draft since in both cases the cooling is mainly by convection, and the cooling by radiation of the outer coil is a small percentage of the total. The data substantiate this idea. Since the radial gradients for fan-cooled coils are higher than for natural draft, the hot spots are slightly more, as might be expected.

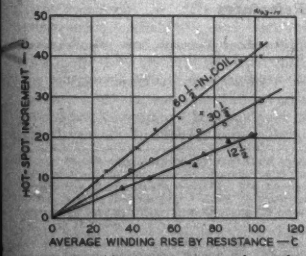

Figure 17. Hot-spot increments for multi-layer outer barrel coils, natural-draft-cooled

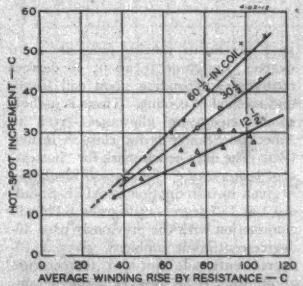

Figure 18. Hot-spot increments for four-strand single-layer inner barrel coils, natural-draft-cooled

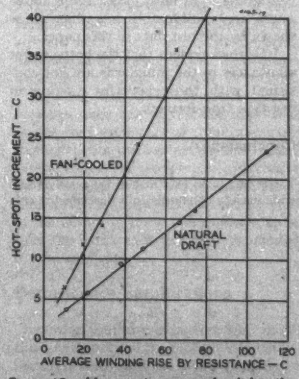

Figure 19. Hot-spot increments for disk coils, natural-draft and fan-cooled

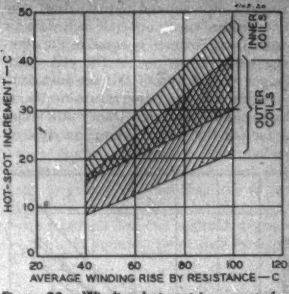

Figure 20. Winding hot-spot increments for natural-draft cooling

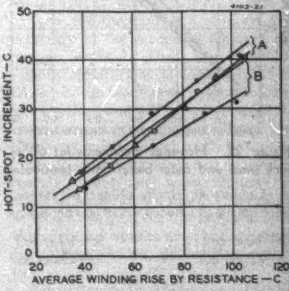

Figure 21. Hot-spot increments for $30^1/_2$-inch inner and outer barrel coils, fan-cooled

A—Cooling-air velocity 530 feet per minute
B—Cooling-air velocity 2,015 feet per minute
⊙—Inner coil △—Inner coil
⊡—Outer coil ●—Outer coil

There is some effect of change of air velocity, the lower velocities giving a higher hot-spot. Due to the fact that higher velocities can be somewhat more easily obtained in directed-flow design than in the random-flow design, there is some advantage in the use of this type of construction as a means of control for hot-spot rise.

A correlation of natural-draft and fan-cooled hot-spot increments for $30^1/_2$- and $60^1/_2$-inch coils, as shown in Figure 23, indicates that the fan-cooled designs may have slightly higher hot spots, especially if low-velocity cooling is used.

Air-Duct Rise as a Function of Winding Rise by Resistance

The air-duct temperature rise is a straight-line function of rise by resistance. It is interesting to note that for medium-

height coils operated natural draft, the temperature rise in one-half-inch-wide air ducts is approximately equal to the average temperature rise of the coil. The height of coil affects this air-duct temperature rise, the temperature rise being higher for longer coils. Duct width is also a factor, the change being roughly inversely proportional to duct width within a limit of usual dimensions.

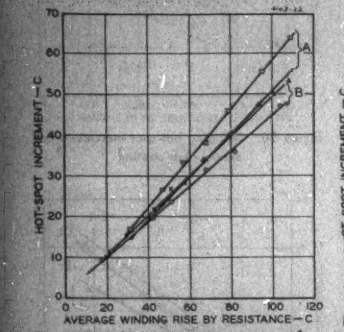

Figure 22. Hot-spot increments for $60^1/_2$-inch inner and outer barrel coils, fan-cooled

A—Cooling-air velocity 490 feet per minute
B—Cooling-air velocity 1,515 feet per minute

⊡—Inner coil ×—Inner coil
△—Outer coil ⊙—Outer coil

Effect of Enclosing Case

The data in this paper were taken mainly with the windings in the open air. This approximates the conditions when expanded metal cases are used. In order to check the effect of a metal-clad case, such as might be provided by a sheet-metal case or the modern-styled louvered case, some runs were made with an enclosing metal shell with openings at top and bottom. The hot-spot increment was not affected within the limits of measurement by the enclosing metal shell.

Discrepancies Between Existing Standards and Test Data

For 55 degrees centigrade rise (class *A* insulation), Tables II and III show hot-spot increments for dry-type transformers ranging from about 11 degrees centigrade for very short natural-draft coils to about 31 degrees centigrade for tall fan-cooled coils. This is contrasted with the flat 10-degree centigrade hot-spot temperature allowance in American Standards for Transformers[1] with class *A* insulation.

For 80 degrees centigrade rise (class *B* insulation), these same tables show hot-spot increments ranging from about 16 degrees centigrade to about 46 degrees centigrade, depending upon coil length and method of cooling. There is no hot-spot temperature allowance given in American Standards for class *B* insulation. The only bench mark for "hottest-spot temperature" for class *B* insulation is given in introduction to AIEE Standard 1 as 130 degrees centigrade. This, in conjunction with the previously used 40-degree-centigrade ambient, gives a 10-degree-centigrade hot-spot temperature allowance. If an average ambient temperature of 30 degrees centigrade is used as given in American Transformer Standards,[1] this allowance becomes 20 degrees centigrade. In most cases, these allowances are considerably less than those shown by the test data in this paper.

It is thus evident that the hottest-spot allowances in the Standards are not consistent with those actually existing in dry-type transformers.

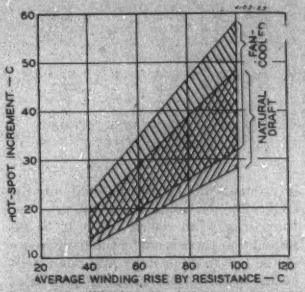

Figure 23. Winding hot-spot increments for natural-draft and fan cooling for $30^1/_2$-inch and $60^1/_2$-inch coils

Conclusions

1. It has been established by tests on the wide variety of sample coils described in this paper that hot spots much greater than heretofore supposed exist in modern dry-type transformers of normal design dimensions.

2. There is no consistent relationship between the temperature rise of the air in the coil duct and the hot-spot temperature increment. In general, this increment is less than one half the air rise for natural-draft cooling and more than one half the air rise for forced-draft cooling.

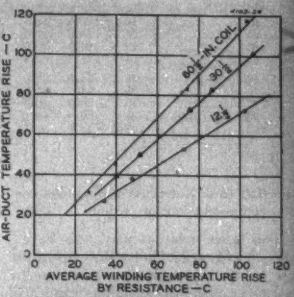

Figure 24. Air-duct temperature rises for barrel-type coils with natural-draft cooling

3. For a given dry-type transformer-coil design, the ratio between the hot-spot temperature rise and the average temperature rise by resistance remains constant when the average temperature rise is varied by changing the load.

4. This ratio increases with coil height.

This ratio is greater for inner coils than for the outside coil.

For a given coil design and air velocities normally used, this ratio is greater for forced-draft than for natural-draft cooling.

This ratio varies somewhat with the type of coil design.

5. No single hot-spot increment applies for all types and ratings of dry-type transformers because of the considerable number of variables affecting the hot spot.

6. The high hot-spot increments found in these tests show the need of review and modification of the conventional allowances for dry-type transformers.

References

1. American Standard for Transformers, Regulators, and Reactors C57.1, 1942.

2. AIEE Standard 1, 1940. Introduction.

Some Aspects of the Application of Induction Motors to Aircraft

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ASSOCIATE AIEE

Synopsis: Fundamental characteristics of the three-phase induction motor are reviewed with respect to their possible application to aircraft. A brief review of present motor specifications is presented, and test data are given on the operation of an induction motor with one or two lines shot away. Common types of motor loading are discussed with reference to the suitability of induction-motor drive for each. Curves are presented to illustrate the characteristics of motors and various types of loading.

USE of electric power in aircraft has grown with each succeeding year. Aircraft have become larger, and with each succeeding increase in size new and greater demands have been made for electric power. To date these demands have been met magnificently by 12-volt and 24-volt d-c systems, and there seems every reason to suppose that these systems will be in use for a long time to come. However, there is a transmission-weight penalty for a 24-volt system on large airplanes, particularly when the total load is high. Therefore, with an eye to the very large planes of the future, the aircraft industry has been fostering the development of two new electric systems, namely, a 115-volt d-c system, and a 208-volt three-phase 400-cycle system. Either of these two proposed systems will reduce greatly the weight of the electric wiring, and each system has its own special merits.

Motors constitute the principal electric load on military aircraft. A knowledge of motor characteristics is essential to a proper application of these motors to aircraft accessories and to the selection of the electric system itself. This paper presents the fundamental characteristics of the three-phase induction motor and some of the problems involved in applying them to aircraft use. The simplicity of construction, reliability, and lack of commutators and brushes recommends this motor very highly. However, there are certain disadvantages which must be considered, such as, lack of a high ratio of starting to running torque and lack of speed control. In addition to these drawbacks the conditions encountered in applying any piece of apparatus to aircraft must be considered. These conditions are much more severe than those encountered in industrial practice. This point can be understood easily when it is considered that an airplane may take off from a steaming jungle and within an hour be at an altitude of from 20,000 to 40,000 feet, where the temperatures are anywhere from −30 degrees centigrade to −70 degrees centigrade; and in a few hours it may fly far enough, so that when the plane lands the temperature would still be from −50 degrees centigrade to −70 degrees centigrade. Of course, this cycle easily could be reversed. In industrial practice it is thought necessary to rerate the motor with changes in temperature and changes in altitude, but an aircraft motor must operate at its rating under all of these conditions. In addition these motors must be light in weight. Compared with their commercial counterparts, they are mere pygmies. This means that each part of these motors is worked to its utmost with a very small safety factor. Therefore, in applying a motor to a given job, care must be taken that additional material is incorporated in the design in those places which must take the extra wear and tear demanded by the application.

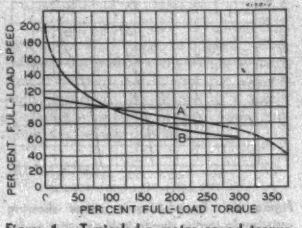

Figure 1. Typical d-c motor speed–torque curves

A. Shunt motor
B. Series motor

Performance Specifications

In order that the engineers who make the applications of the motors, and manufacturers who build the motors, may have a common language and understand each other properly, the United States Army Air Forces together with the manufacturers of motors have written a preliminary performance specification. They first picked a foundation frequency. This frequency is 400 cycles per second, which is a compromise between the 800 cycles per second that has been used for aircraft radio and the 240 cycles per second that was believed best for motors. Since this preliminary specification does tend to give a common language or picture of the motors, and since it does give a basis on which they can be rated, a review of the more common points will be found in Table I.

Speed–Torque Characteristics

For years the aircraft industry has been using small 12- and 24-volt d-c motors to perform the thousand and one odd jobs necessary to the successful flight of the modern airplane. Those who make the various applications of these motors to these jobs are familiar with the characteristics of them and will recognize easily the speed-torque curves given in Figure 1 as the characteristics which apply to the two types of d-c motors most used on aircraft namely, shunt and series motors. In order to apply an a-c motor successfully to these same jobs, the torque characteristics of the a-c motors must become familiar to those who are making the application.

Figure 2 gives typical torque curves for the two classifications of polyphase induction motors given in the table. These curves have been smoothed. Under ordinary conditions the curves for these individual motors are not smooth, but they are filled with small ragged variations caused by the distribution of flux in the motor and the winding distribution of the motor. Figure 3 shows one example of an actual curve of a motor with all the important variations. This curve was taken in the normal manner by taking readings at set points. Therefore, it does not show all of the minute individual

Table I. Motor Performance Specification

	Continuous-Duty Motors	Intermittent-Duty Motors
Frequency	400	400
Line voltage	200	200
Duty cycle	Continuous	1 minute in 20
Allowable frequency variation	±5%	±5%
Allowable voltage variation	±10%	±10%
Combined variation of voltage and frequency	±10%	±10%
Locked rotor torque in per cent of full-load torque	160%	300%
Breakdown torque in per cent of full-load torque	200	None specified
Pull-up torque in per cent of full-load torque	140	None specified

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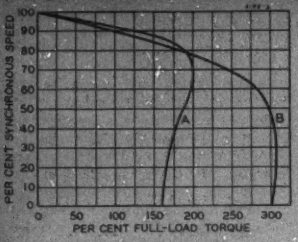

Figure 2. Typical smoothed speed–torque curves for induction motors

A. Continuous-duty motors
B. Intermittent-duty motors

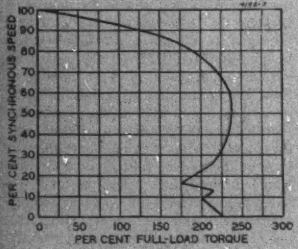

Figure 3. Test speed–torque curve showing irregularities

variations which would be recorded by oscillographic means. In using curves of this type it must be remembered that they apply only at rated voltage unless otherwise specified. When the voltage and frequency variations that are expected are taken into account, these curves vary as shown in Figures 4 and 5. Figures 4 and 5 give the maximum variation of the speed-torque curves for a variation of plus or minus ten per cent in voltage. This is the worst condition which can occur and still be within the limits specified by the Army Air Forces.

It should be emphasized that the curves included to illustrate general performance were obtained by assuming a certain set of constants for these motors. To make any application study a definite design curve should be obtained from the motor supplier.

Motor Operating Speed

The aforementioned curves have been plotted on the basis of per cent rated torque and per cent synchronous speed. For the 400-cycle system, the following motor synchronous speeds are possible: 24,000 rpm, 12,000 rpm, 8,000 rpm, 6,000 rpm, 4,800 rpm, 4,000 rpm, 3,428.50 rpm, and 3,000 rpm. These speeds are the synchronous speeds for 2-, 4-, 6-, 8-, 10-, 12-, 14-, and 16-pole motors, respectively. In general, a lighter power unit can be obtained by using the higher-speed motors and gearing down to the speed desired rather than using a motor with a large number of poles. Some idea of the change in weight with the change in the number of poles can be obtained when it is considered that an eight-pole one-horsepower motor has about 1¼ times as much active material as a four-pole one-horsepower motor. Nearly all three-phase induction motors run within a few per cent of their synchronous speed at full load. This can be seen easily by examining the curves in Figures 2, 3, 4, and 5. Further examination of these curves show that, even under conditions of high overload, the speed of the motor is still relatively close to the synchronous speed. For this reason an induction motor is known as a constant-speed type of power source. Where speed control is desired this constancy of speed in the

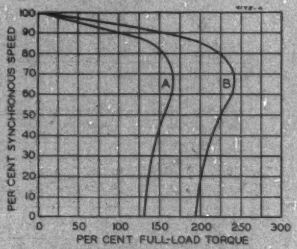

Figure 4. Speed–torque curves showing variation in torque due to voltage variation for [illegible] continuous-duty motors

A. Speed–torque curve at 90 per cent voltage
B. Speed–torque curve at 110 per cent voltage

induction motor is one of its chief disadvantages. Speed is set by frequency and by certain constants in the motor, and therefore cannot be varied for an individual motor. Compare this constancy of speed with the speed-torque curves as shown for the main types of d-c motors in Figure 1. The series motor has a very large change in speed from no load to full load, and with overload the change becomes correspondingly greater. The shunt motor more closely resembles the induction motor. However, it has relatively large differences of speed between individual motors. This is not true of the induction motor, since its speed is regulated almost entirely by frequency. According to National Electrical Manufacturers Association Standards, the speed of a shunt motor at full load may vary plus or minus 7.5 per cent within a group of motors, whereas for the induction motor the speed variation among a group of motors is apt to be more nearly in the region of one half of one per cent.

In addition all d-c motors are subject to a speed variation with input voltage which may be nearly as great on a percentage basis as the per cent variation of the input voltage. Induction motors' speed varies very little with the input voltage. Figures 4 and 5 show the approximate amount of variation that can be expected. However, the speed of an induction motor does vary with frequency, and, therefore, a variation of approximately plus or minus five per cent can be expected because of frequency change.

Locked-Rotor Inputs

Locked-rotor inputs affect the size of the feeders and protective devices and are, therefore, of interest to the aircraft-system engineer. It is impossible to give aircraft values applying to all cases, but the figures given in the Table II represent normal values that may be expected for three-phase 200-volt 400-cycle induction motors.

If, as often happens, the voltage under locked-rotor conditions is less than rated, the inputs will be reduced; the torque, kilowatts, and kilovolt-amperes will vary as the square of the voltage, the amperes will vary directly as the voltage, and the power factor will remain constant.

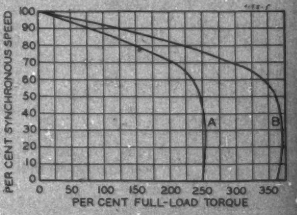

Figure 5. Speed–torque curves showing variation in torque due to voltage for intermittent-duty motors

A. Speed–torque curve at 90 per cent voltage
B. Speed–torque curve at 110 per cent voltage

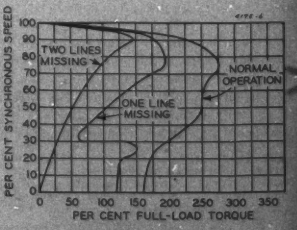

Figure 6. Test speed–torque curves of a three-phase four-wire induction motor showing the effect of having one and two lines shot away

Motor Temperature and Altitude

Most of the motors designed for use in aircraft are designed to be cooled by a self-driven fan. The amount of cooling depends upon the differential of temperature between the cooling air and the motor and upon the density of the air. Motors normally are designed to operate at various altitudes with temperatures per the National Advisory Committee for Aeronautics Standards charts. If the motor is subjected to ambient temperatures other than those given on these charts for the various altitudes, the motor must be more conservatively designed and therefore heavier in weight.

Motor Operation With One and Two Wires Shot Away

In the installation of d-c motors one wire and a ground is usually used. With this installation, if the one wire is shot away, the motor stops. The a-c motor has three line leads and the neutral grounded. If one or two line leads are shot away, the motor will still continue to run, in most cases, though it may not necessarily start if it is once stopped. Figure 6 shows the test speed-torque curves of a motor that was designed to drive a generator which was subjected to overloads of short time duration. This motor was designed, therefore, to have a rather high pullout torque point with respect to full-load torque. Tests were taken with one line open and two lines open. The results are shown in Figure 6. Note particularly the cusp that occurs at one-third synchronous speed with one line open. The size of this cusp varies with the winding of the motor. For some motors the torque actually may go negative at this point. If this occurs in a particular motor it would never accelerate to its normal running speed. A motor having the torque characteristic with one line open such as shown in Figure 6 would accelerate to full running speed providing the torque loading was light. With two lines open, the motor would be running on single phase power and would act as a single phase motor with no auxiliary winding for starting purposes. As long as it is running, it would continue to run provided it was not too heavily loaded. Once it stopped, it would not automatically start itself when power was supplied. A motor operating with either of the two conditions—one or two lines open—would not last long but would soon burn itself out or operate any thermal protection device that might be applied. Considering the multi-circuit wiring systems that have been laid out for the a-c systems, however, the chance of a motor operating with either of these two conditions is extremely remote.

Table II

	Continuous Duty	Intermittent Duty
Torque, in per cent of full load	160	300
Kilowatts per horsepower	2.4	3.5
Power factor	0.50	0.60
Kilovolt-amperes per horsepower	4.8	5.8
Amperes per horsepower	14	17

Motor Loads

Some of the other characteristics that affect the application of the motors can best be brought out by considering some of the different types of loads that occur in an airplane. Many of these loads do not occur singly but in combination. Because of the multiplicity of combinations, only the more common types of load will be illustrated here.

Consider first the fan type of load. This load has a torque characteristic which varies as the square of the speed. Figure 7 shows a continuous-duty motor characteristic with a fan-torque characteristic superimposed. It will be noticed that this motor at sea level is loaded to full load. Quite obviously there is no starting problem for a strictly fan load. But note what happens to the load on the motor at 30,000 feet. Since the induction motor is practically a constant-speed motor, the torque loading goes down as the density decreases. Compare this with the fan operated by a series motor as shown by Figure 8. Here, as the torque loading decreases with density, the motor tends to speed up, thus partially compensating for the decrease in density. Thus with two motors of identical rating the series motor would drive the fan in such a way as to deliver more pounds of air at high altitude. With the induction motor the load at 30,000 feet has dropped to approximately 48 per cent of the sea-level value, while with a series motor it has decreased to only 66 per cent. With a series motor even less drop in load can be obtained by operating on a steeper portion of the torque curve. If such compensation is desired with the induction motor, other means of control must be used.

Another type of load which is encountered very commonly is the so-called friction-type load. This type of loading is usually considered to have constant friction or torque over a large range of speed. If it is remembered that these friction loads generally are made up of bearings and gear losses, it can be seen that they are not constant but vary considerably with the consistency of the lubricant. Very few lubricants are not affected by extremes of temperature encountered in aircraft. Even the friction between two rubbing surfaces changes with temperature and the condition of the surfaces. Thus, the assumption that a friction load is a constant-torque load is false. Only if all conditions of temperature and surface are maintained constant can it be expected that the friction loads will be constant. In making any application of a motor to a friction load the maximum torque required should be deter-

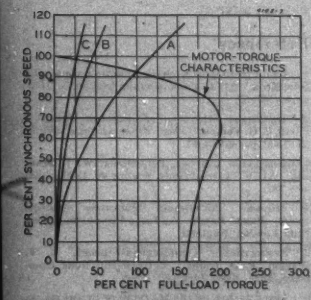

Figure 7. Polyphase induction motor driving a fan

A. Fan speed-torque curve at sea level
B. Fan speed-torque curve at 30,000-feet altitude
C. Fan speed-torque curve at 40,000-feet altitude

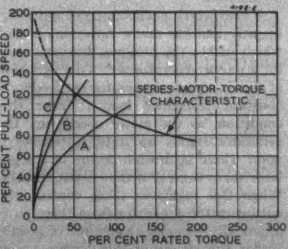

Figure 8. Fan load on a d-c series motor

A. At sea level
B. At 30,000 feet
C. At 40,000 feet

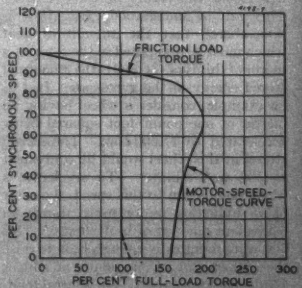

Figure 9. Polyphase induction motor driving a pure friction load

mined for the worst conditions of temperature and surface that can be expected. Most friction loads are characterized by having a relatively high breakaway torque, that is, the coefficient of friction is higher under static than under running conditions. Because of the relatively low starting torque of continuous duty induction motors this may become the limiting factor. Figure 9 illustrates a pure friction load with no allowance for variation due to temperature and surface conditions.

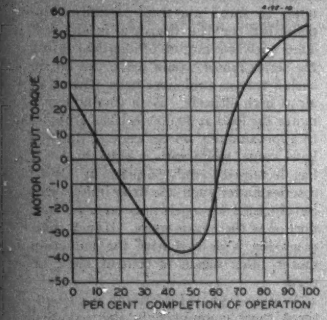

Figure 10. Motor torque in carrying out an intermittent-cycle operation having an overhauling load

Probably one of the most interesting types of application, not so much from a motor standpoint as from a control standpoint, is the operation of inertia-type loads. Gyroscopes driven by motors are used in many of our best weapons today. These units generally require very little running torque, since the only thing which tends to stop them is a slight amount of bearing friction and some windage about the outside surface of the gyro. Therefore, the tendency is to apply relatively very small motors to these units. Care must be taken, however, that adequate surface is provided to dissipate heat from the rotors of these motors. This can be understood easily if it is remembered that the amount of heat which must be dissipated in the rotor of a motor of this type is equal to the amount of stored energy in the gyroscope. Just as an example, consider a wheel having an inertia of one pound-foot squared being accelerated to 11,500 rpm. The energy stored in this wheel would be equivalent to 500 watt-minutes. To accelerate a wheel of this size to this speed, the rotor of an induction motor must absorb an equivalent amount of heat energy. This 500 watt-minutes is enough heat to raise the temperature of one pound of copper 175 degrees centigrade. The general tendency for applications of this sort is to use motors whose rotors weigh much less than one pound. In order to provide the necessary cooling the accelerating time must be extended, or additional cooling area must be provided for the rotor. One of the best tricks for application of this kind is to turn the motor inside out, so that the rotor becomes part of the rotating wheel and therefore has a large mass and heat-storage capacity.

Overhauling loads seldom are encountered by themselves but are generally a part of a cycle operation. Figure 10 illustrates a cycle of operation of an actuator in which an overhauling load occurs. The a-c induction motor is ideal for this type of application, since, if the motor is accelerated to only a few per cent above the synchronous speed, it will absorb approximately as much mechanical power as it would put out if it were running that per cent below synchronous speed.

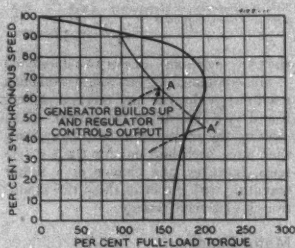

Figure 11. Regulated generator feeding a constant load driven by a three-phase induction motor

In other words, it becomes an asynchronous generator and feeds electric power back into the rest of the system. Motors handling loads of this type, of course, must be able to deliver sufficient torque to take care of the highest requirements of the cycle. Generally speaking, however, these cycles are of relatively short duration, and the cycles occur so infrequently that an intermittent-type motor can be used satisfactorily. The cycle illustrated in Figure 10 takes about 30 seconds.

A load which is encountered quite frequently and has many variations is that which makes the motor a driving means for a motor generator set. One variation of this is a motor generator set feeding a constant resistance load. Under this condition, as the motor speeds up, the generator builds up until it reaches a point where saturation occurs or a regulator takes control of the output voltage. When this regulator takes control, the output of the generator from there on is practically a constant amount of power. Under this condition the torque varies inversely as the speed. An examination of Figure 11 will show that a condition very easily could be encountered in which the motor generator set would build up to full voltage at a relatively low speed, and the motor would never accelerate beyond point A, as shown on the curve. If the generator built up to full voltage and the regulator took control at approximately 46 per cent of the synchronous speed of the motor, as shown on Figure 11, the point A would coincide with A' at 200 per cent of full-load torque. The motor would accelerate to about 50 per cent of full-load speed and run there. Another variation of the motor-generator-set application is one in which the motor generator set feeds a variable-type load, and the motor generator set is controlled in such a way that under starting conditions the maximum demand can be put on the generator. This type of motor generator set is often used in certain control circuits for actuating devices. Then there is the third type of motor generator set in which the excitation is constant. This motor generator set has a rather definite torque characteristic and does not present the problems which may occur with the others.

The preceding applications illustrate but a few of the many that occur on aircraft. There are a myriad of combinations of the fundamental loads that can occur. Each combination should be broken down and studied with respect to all of the conditions that may be encountered. Induction motors have been used in commercial practice for many years. Their simplicity, ruggedness, and lack of commutating or slip-ring brushes have given them an advantage which far outweighs the few disadvantages they may have. Similarly, in aircraft these same advantages will stand out more clearly with each succeeding application and their reliability and ease of maintenance when compared with the d-c motor with its brushes and commutator will lead to an everspreading use of the induction motor to do the hundreds of odd jobs that are of vital necessity to the modern aircraft.

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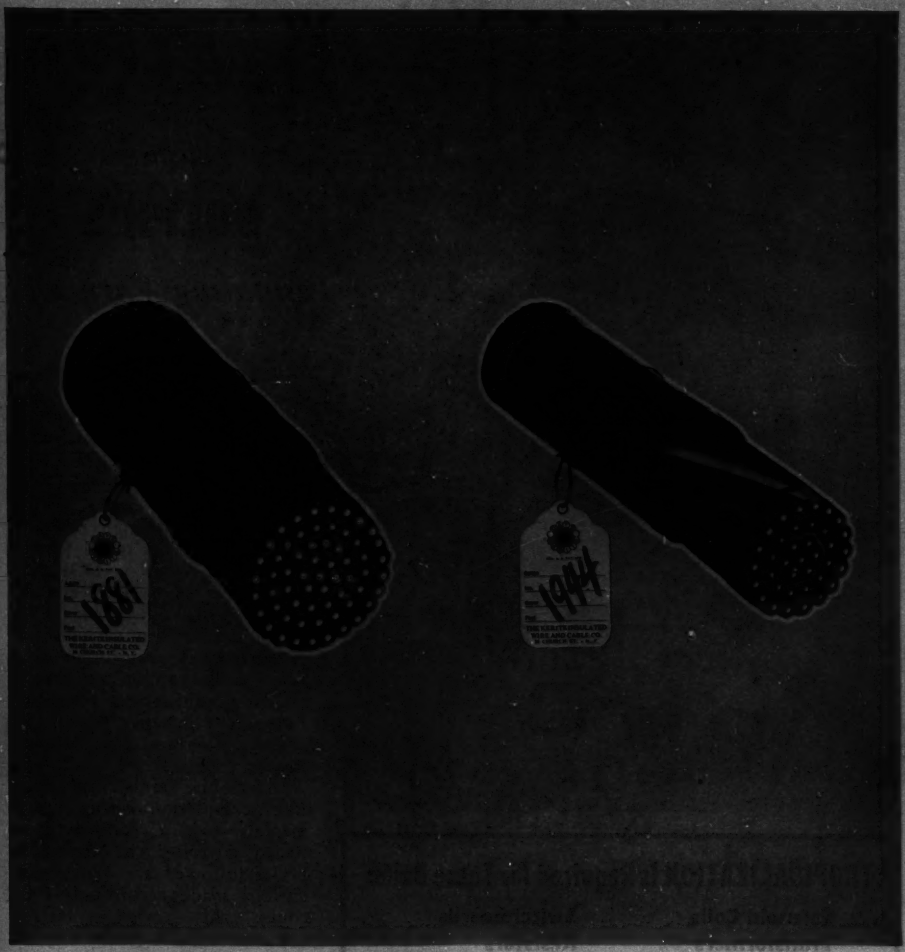

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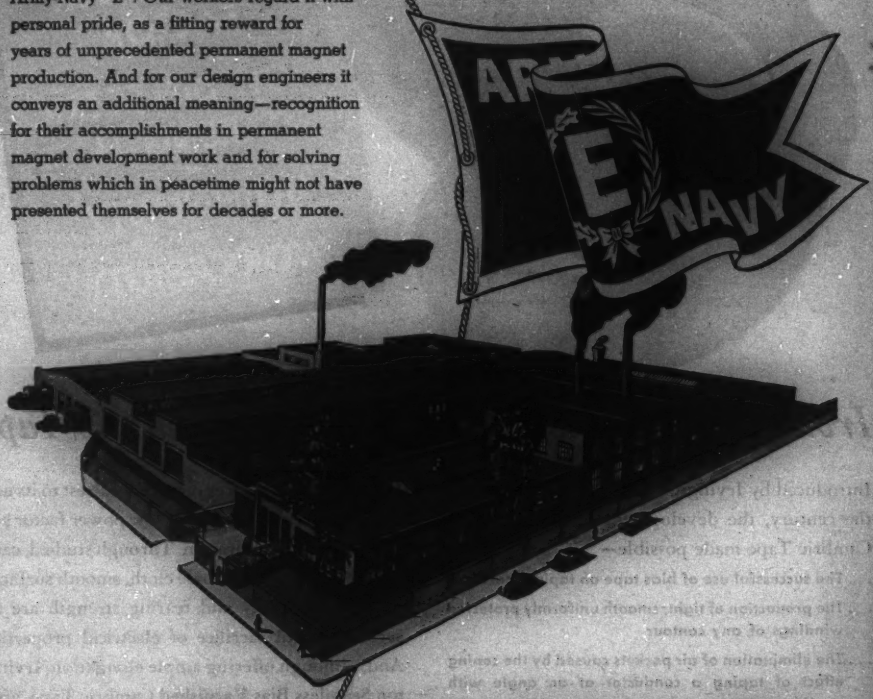

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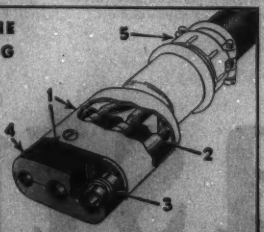
4. Insulation extends beyond armor eliminating danger of short circuiting.
5. Designed for use with standard AN cable clamps.

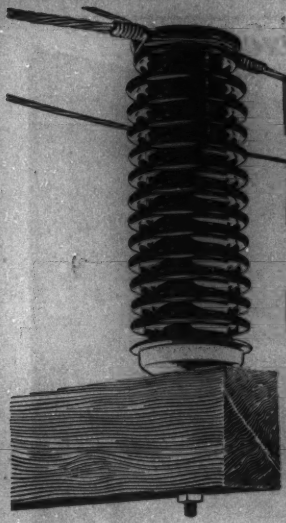


TRADE HUBBELL MARK

HUBBELL

DEVELOPMENT LABORATORY OF HARVEY HUBBELL, INC.

1559 STATE ST., BRIDGEPORT 2, CONN.

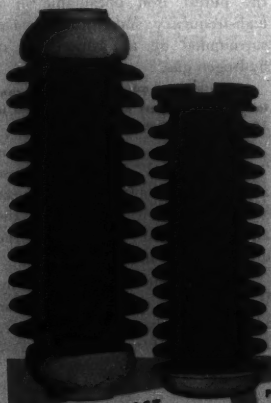


WARTIME CONSTRUCTION

need not be "TEMPORARY CONSTRUCTION"

TRANSMISSION LINES
ON WOOD POLES AND
LAPP LINE POSTS
ARE LONG-LIFE,
LOW-TROUBLE LINES . . .
. . . THAT GO UP
FAST AND USE A
MINIMUM OF MATERIAL

• On a cost-per-year basis, transmission line construction on wood poles with Lapp Line Posts is most practical and economical. And today, if load demands make it necessary for you to build a new line under war-emergency restrictions, you'll find this same construction will require least in critical materials, least in man power. The extra height of Lapp Line Posts will give your line better clearance, or even in some cases permit use of shorter poles. Coordinate necessity measures with your long-time planning and build low-cost long-service lines—on Lapp Line Posts.



Lapp

LAPP INSULATOR COMPANY, INC., LE ROY, N. Y.

LAPP LINE POST and STATION POSTS on your system offer . .

POWER ARCOVER. Flashover and leakage distances are not appreciably lowered by damage—even loss of several petticoats.

NO CRACKING. One piece post body, not subject to bursting from tension strains created by thermal changes in nested parts.

NO CLEANING. Fog-type design preserves uniform leakage path, prevents leakage flashover, makes the unit "self-cleaning."

NO PUNCTURE. Puncture path in Lapp Post design is as great as flashover path. Insulator will flash over rather than puncture.

RADIO INTERFERENCE. By virtue of design factors alone, radio interference is permanently prevented at rated neutral voltage.

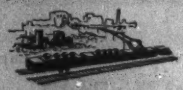
MECHANICAL RUGGEDNESS. Stones or bullets deflect off, or rupture petticoats, leaving post body intact and insulator secure.

KEEPING UP WITH

Electricity

SYNTHETIC FIREFLIES . . . New Westinghouse fluorescent marker lamp rivals the firefly in economy of light generation. Tiny lamp, consuming only 1/10th watt, will prevent mishaps on dark stairsteps. Unlike lightning bug, it can be kept glowing continuously—at practically no cost.

1/50,000,000th OUNCE . . . That's the weight of a single layer of oxygen atoms the size of an airmail stamp. Westinghouse research engineers have built a delicate balance that measures the weight of such a microscopic layer of oxide on metal—to determine resistance of special alloys to high temperatures.



POWERHOUSE ON WHEELS . . . The retreating enemy knows that the quickest way to paralyze a city is to destroy its powerhouse. Advancing Allies know that the quickest way to restore order is to restore power. A 5000 KW power train, built by Westinghouse, moves in on railroad tracks, hooks up to power lines, starts boiler and generator . . . then lights come on, order emerges.

INSIDE STORY . . . Transparent Lucite bearings now permit research engineers to visualize performance of lubricating oil in bearings, subjected to varying operating speeds and pressures. Red pigment shows where oil goes and what it does.

PREFORMED PLASTICS . . . New Westinghouse process in plastics manufacture "beats" resins into cellulose fibre, then shapes mixture over perforated copper form. Plastic is peeled off and dried, then placed in heated mold and pressed into final shape. Saves time in making reinforced plastics of intricate shapes.

Portrait of a Scientist

creating a better yardstick for testing wartime metals

Spectrum analysis provides the *quickest* and *most* accurate method for checking the composition of metals used in making guns, planes, tanks and ships.

Iron has long been used as a *yardstick of comparison* in spectrography—because of the large number of lines in the iron spectrum.

Formerly, the best standard obtainable was *iron only 99.9 per cent pure*—containing impurities that produced confusing lines in spectrographic pictures.

Westinghouse research engineers tackled the difficult problem of producing a purer iron—a *better* yardstick for testing wartime metals.

They accomplished this by fusing the purest iron obtainable in a high-frequency induction furnace, surrounded by an atmosphere of hydrogen gas.

Result: iron 99.99 per cent pure—containing only 1 part metallic impurities in 10,000 parts of absolutely pure iron!

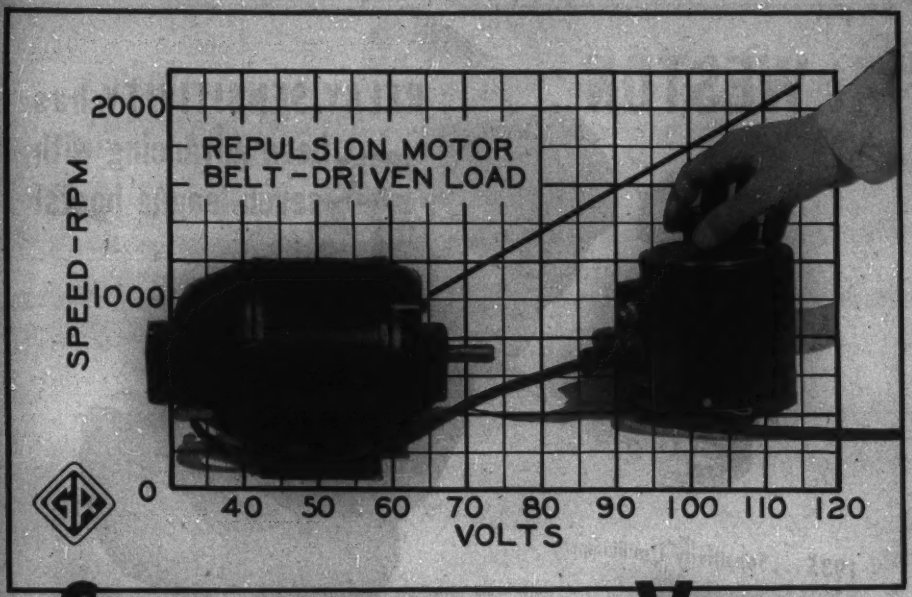
Today, this ultra-pure iron is "mass-produced" by Westinghouse at the rate of 1000 pounds per year—and is used in all parts of the anti-Axis world to improve the quality of war material.

A significant contribution, by Westinghouse, to industry at war and in the days of peace to come. *Westinghouse Electric & Manufacturing Company, Pittsburgh 30, Pa.*

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

WESTINGHOUSE PRESENTS John Charles Thomas, Sunday 2:30, EWT, NBC. Ted Malone, Monday, Wednesday, Friday 10:15 pm, EWT, Blue Network.



SPEED CONTROL—WITH VARIACS

VARIAC continuously adjustable auto-transformers are widely used to control the speed of fractional horsepower motors. They provide exceptionally smooth control with very low power losses. This type of control, however, cannot be used successfully with all a-c motors; both the type of the motor and the type of load determine whether the variable auto-transformer can be used.

For example, repulsion and series motors can be controlled over a wide range of speeds; induction motors do not lend themselves to voltage control, except with a fan-type load where the effective load varies greatly with speed.

The split-phase motor with automatic cut-out cannot be controlled successfully. Repulsion-start induction motors can be controlled only during the time that the repulsion-start system is cut in, and if the repulsion winding is designed for continuous duty.

Variacs are incorporated in so many motor-operated devices that many manufacturers now consider the adaptability of this control when choosing or designing the motor to be used.

A detailed discussion of Variac motor speed control appears in a recent issue of the G-R EXPERIMENTER. May we send you a copy?

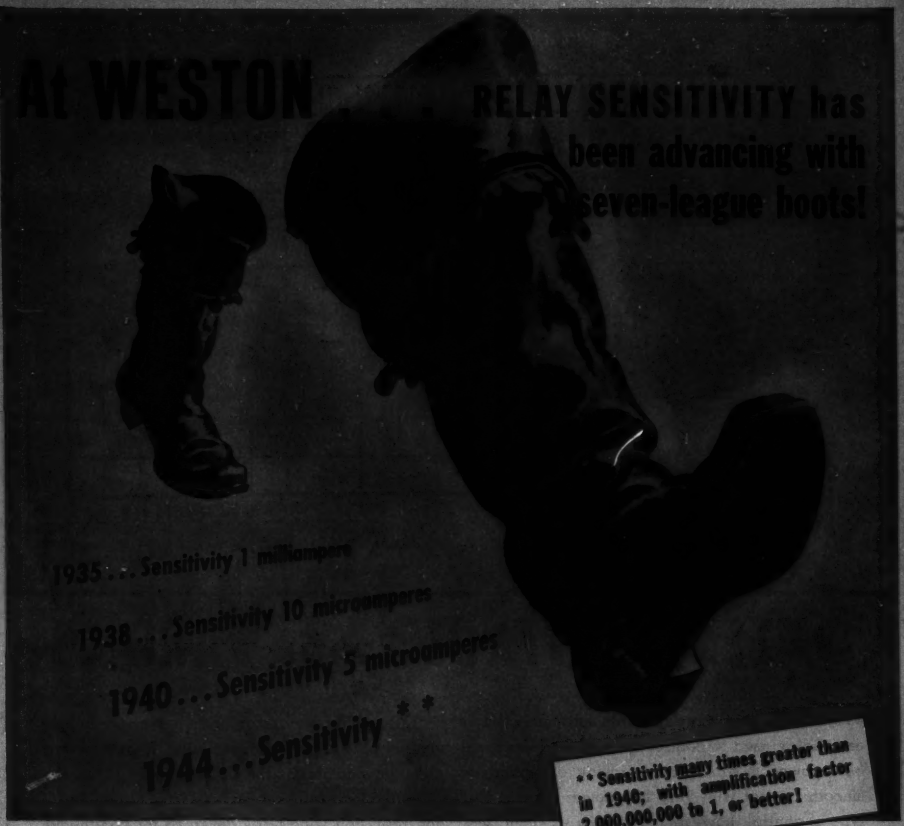
VARIAC

VARIACS are available (with suitable priority rating) in power ratings between 170 va and 7,000 va; prices are $10.00 to $100.00.

● **WRITE FOR BULLETIN 890**

MADE ONLY BY **GENERAL RADIO COMPANY**

Cambridge 39, Mass.
NEW YORK
CHICAGO
LOS ANGELES


At WESTON . . . RELAY SENSITIVITY has been advancing with seven-league boots!
1935 . . . Sensitivity 1 milliampere
1938 . . . Sensitivity 10 microamperes
1940 . . . Sensitivity 5 microamperes
1944 . . . Sensitivity * *
** Sensitivity many times greater than in 1940; with amplification factor 2,000,000,000 to 1, or better!

With today's emphasis on electronics, WESTON developments in the field of Sensitive Relays assume utmost interest to design engineers. Even prior to the war, these relays provided positive control at input values low as 2 microamperes or 1 millivolt. Employing WESTONS exclusive *magnetic contact* principle, they handled 5 watts at 110 volts, with complete freedom from contact troubles.

But relay development at WESTON has kept pace with the more exacting *control* needs of this war. Relays with sensitivity *for exceeding* that of pre-war days already have proved their reliability on critical equipment, and under the most rigorous conditions!

More than likely, these relays provide the answer for many of tomorrow's products; for they provide the simplest, most compact means of controlling at minute energy levels.

Have the full story on "what's ahead" in sensitive relays and instruments at your fingertips. Check WESTON, too, on all *war instrument* needs!

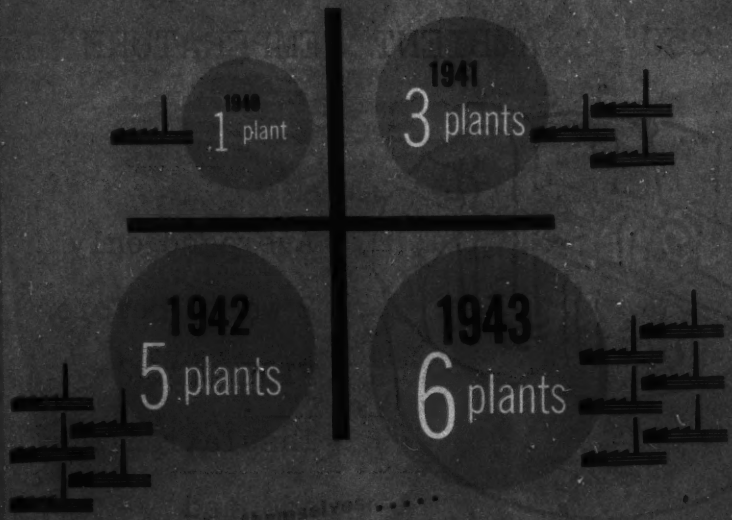
Laboratory Standards . . . Precision DC and AC Portables . . . Instrument Transformers . . . Sensitive Relays . . . DC, AC, and Thermo Switchboard and Panel Instruments.

WESTON

Specialized Test Equipment . . . Light Measurement and Control Devices . . . Exposure Meters . . . Aircraft Instruments . . . Electric Tachometers . . . Dial Thermometers.

Weston Electrical Instrument Corporation, 664 Frelinghuysen Ave., Newark 5, N. J.

an outstanding record of achievement



With the skill and experience of 34 years of capacitor specialization, Cornell-Dubilier meets the urgent needs of war production. Since 1910, thru every phase of capacitor development, our growth parallels that of the electronic industry. We have not only kept pace with it but have anticipated new trends.

Today there are more C-D capacitors in use than any other make. This tremendous increase in production has been accomplished while maintaining C-D's high standards of quality and dependability. Our name is synonymous with reliability . . . that's why C-D's are first with 4 out of 5 engineers. Our facilities and specialized skills are at your service. Write today to Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey.

TYPE YAT compact, low capacity Dykanol "O" bypass capacitor; hermetically sealed; in specially-treated, drawn metal containers. Range at 600V, .05 mfd. to 1 mfd. Range at 100V, .05 mfd. to .5 mfd.

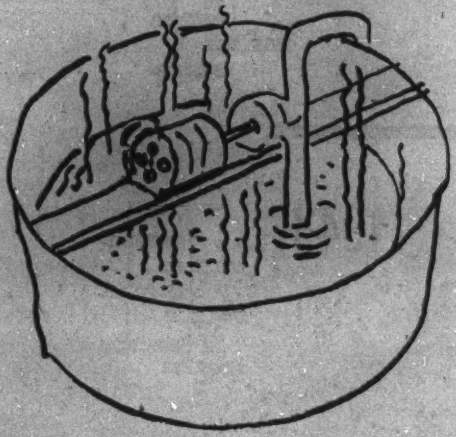
Cornell-Dubilier Capacitors

MICA • DYKANOL • PAPER • WET AND DRY ELECTROLYTICS

WORLD'S LARGEST MANUFACTURER OF CAPACITORS

A FIBERGLAS* CASE HISTORY

MOTOR NOW RUNS MONTHS IN 250° F. AMBIENT TEMPERATURE



Averaged only 2 weeks before FIBERGLAS Insulation was adopted

A nationally known die-casting company was confronted with this problem: its metal-melting tanks required motors to drive pumps located directly above the tanks. These motors were installed 18 inches above the surface of the molten metal, in an ambient temperature of about 250° F.

Motors wound with organic insulation lasted, on the average, only about two weeks before the windings failed. As a solution, these motors were rewound with Fiberglas inorganic insulation—and six months later were still giving continuous service *without a single winding failure!*

This performance is typical of Fiberglas-insulated motors—but is only one of the advantages. When properly applied and impregnated with the correct varnish, Fiberglas insulation also gives exceptional performance in conditions of severe moisture, acid and vibration.

What Is Fiberglas?

Fiberglas electrical insulation is made from strong, fine glass fibers which are twisted into yarns, wound on wires, woven into tapes and cloths, braided into sleevings and formed into cords and other forms required for motor insulation. As a rule, Fiberglas insulation occupies no more space inside the motor than organic tapes, and much less space than equivalent inorganic materials. And, because Fiberglas does not deteriorate with age, it is the ideal insulation for stand-by motors—even though an organic insulation seems sufficient from an operational point of view.

Ask your motor manufacturer about Fiberglas-insulated motors. Or, if you are having motor failures, ask your repair shop to use Fiberglas on your next rewind job.

Fiberglas electrical insulations are immediately available. For complete information, consult your distributor or write *Owens-Corning Fiberglas Corporation, 1859 Nicholas Building, Toledo 1, Ohio. In Canada, Fiberglas Canada, Ltd., Oshawa, Ontario.*

FIBERGLAS *ELECTRICAL INSULATIONS*

*T. M. Reg. U. S. Pat. Off.

ARMY E NAVY

YARNS • TAPES • CORD • SLEEVING • CLOTH AND OTHER FORMS

Laytex Proved Even Better Than We Knew!

We knew that Laytex-insulated wire was good. But actually, no one expected any single wire to stand up to all the tough war-usage that Laytex did.

Laytex has taken arctic cold, tropic heat, moisture, mold, shock and wear, as no other wire has ever done heretofore. It has been used for virtually every purpose a wire can be used for—action-tested all over the world—and has come out with flying colors.

Laytex has a proven record of delivering *more* electricity, *more* dependably, in *more* jobs than any other wire we know.

Right now the entire output of Laytex Wires and Cables is going to the Armed Forces. But the day is steadily drawing nearer when manufacture will be resumed for Buildings, Police and Fire Alarms, Communications, Signalling, Power, Control, and other exacting services.

RUBBER INSULATION AT ITS BEST

U.S. Laytex

Reg. U. S. Trade Mark

WIRES AND CABLES

SERVING THROUGH SCIENCE TO PIONEER A NEW ELECTRICAL ERA

UNITED STATES RUBBER COMPANY

1230 SIXTH AVENUE · ROCKEFELLER CENTER · NEW YORK 20, N. Y.

RCA-8008

A NEW MERCURY-VAPOR RECTIFIER FOR HEAVY-DUTY INDUSTRIAL AND BROADCAST SERVICE

FREEDOM FROM ARC-BACKS

LOW VOLTAGE-DROP

HERE'S a new RCA rectifier developed to meet the needs of continuous heavy-duty industrial and broadcast service. Electrically identical to the improved RCA 872A/872, the 8008 has an extra-heavy base with large pin-contact area. Can replace the 872, 872A, or 872A/872 if socket changes are made. The 8008 is built for long life and high dependability, and like all RCA tubes is backed by continuing RCA engineering and research.

If you have a problem in the application of tubes to industrial or radio service, our engineers may be able to help you. Address: RADIO CORPORATION OF AMERICA, Commercial Engineering Section, 735 South 5th Street, Harrison, New Jersey.

Remember — the Magic Brain of all electronic equipment is a Tube, and the fountain-head of modern Tube development is RCA.

STURDY CONSTRUCTION... HEAVY BASE

LARGE PIN-CONTACT AREA

TECHNICAL DATA

Fil. Volts	5.0
Fil. Amp.	7.5
Max. Peak Inverse Plate Volts (Condensed-mercury temp. of 20° to 60°C)	10,000
Peak Plate Current, Amperes	5
Average Plate Current, Amperes	1.25
Tube Drop, Volts (approx.)	10

RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION · CAMDEN, N. J.

Another Step Up In Heat Resistance of Electrical Insulation

NATIONAL SILICONE-TREATED MICAGLAS COILS, GLASS TEXTILES AND MICAGLAS

Up to this time the usefulness of the **heat-resisting** qualities of Micaglas and other Class B insulating materials has been limited because of the relatively low heat-resistant properties of even the best conventional varnishes, bonds and fillers.

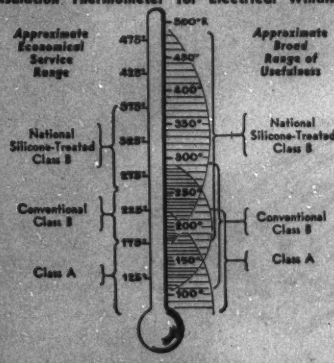
Now Silicone resins have been developed. Extensive tests indicate that some of them will withstand constant temperatures more than 100° F. higher than the previous high point. The net result is that resistance to damage from heat is raised to that extent.

We have combined these new Silicone resins with glass textiles and Micaglas to allow greater use of the heat-resistant qualities of glass and mica.

An idea of the tremendously important result gained is seen in the fact that insulation so treated remains flexible under 482° F. for 50 hours. At continuous 270° F. for ninety days National Silicone-treated coils showed only slight aging. The conventional varnish used in Class B coils of the same kind in the same test was completely disintegrated.

So important is this new technique to operators of rotating electrical machines that it ranks in importance with the introduction of asbestos and fiberglas as a second great step forward in the battle against heat damage.

Insulation Thermometer for Electrical Windings



Much Longer Life for Over-Heated Electric Windings

Obviously, National coils insulated with Silicone-treated Fiberglas or Micaglas offer relief to the operator who is compelled to overload his motors or to operate them in high ambient temperatures. Increased life and reduced coil trouble result. Where either continuous or intermittent heat at or somewhat above the upper limit of conventional Class B insulation causes trouble, National Silicone-treated insulation will vastly improve performance.

Note that Silicone does not affect the heat-resisting qualities of the materials with which it is used. It simply replaces less heat-stable bonding agents and fillers whose low heat-damage levels prevented utilization of the excellent properties of glass, mica, etc., at higher temperatures.

Please Note

Several limiting factors in the use of Silicone varnishes must be taken into consideration. Motor bearings are subject to heat damage. Electrical joints should be brazed rather than soldered. The copper in commutators and slip rings anneals at the curing temperature of Silicone varnishes.

Silicone varnishes should not be used indiscriminately. ***Because of factors other than heat, conventional varnishes may often be used advantageously.***

AVAILABILITY

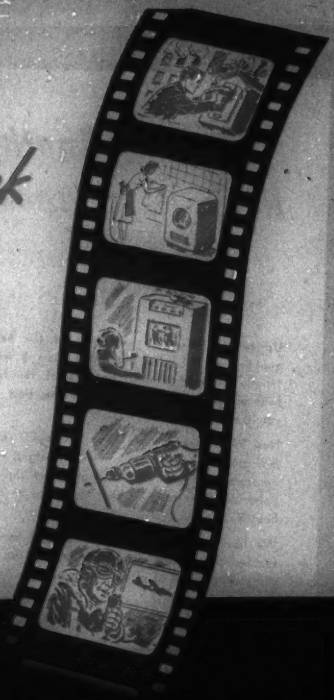
National Silicone-bonded Fiberglas and Micaglas are already available in restricted quantities. National Silicone-treated sleeving, tubing and similar products are in production, but not yet in sufficient quantities for unlimited use. National Silicone Fiberglass and Micaglas insulated coils can now be produced in limited quantities. If heat is causing persistent trouble give us the facts.

Copyright 1944, National Electric Coil Company, Columbus, Ohio

NATIONAL ELECTRIC COIL COMPANY
COLUMBUS, OHIO
ELECTRICAL ENGINEERS: MAKERS OF ELECTRICAL COILS AND INSULATION
BLUEFIELD, W. VA.
DESIGNING AND REPAIRING OF ROTATING ELECTRICAL MACHINES

WORTHY OF

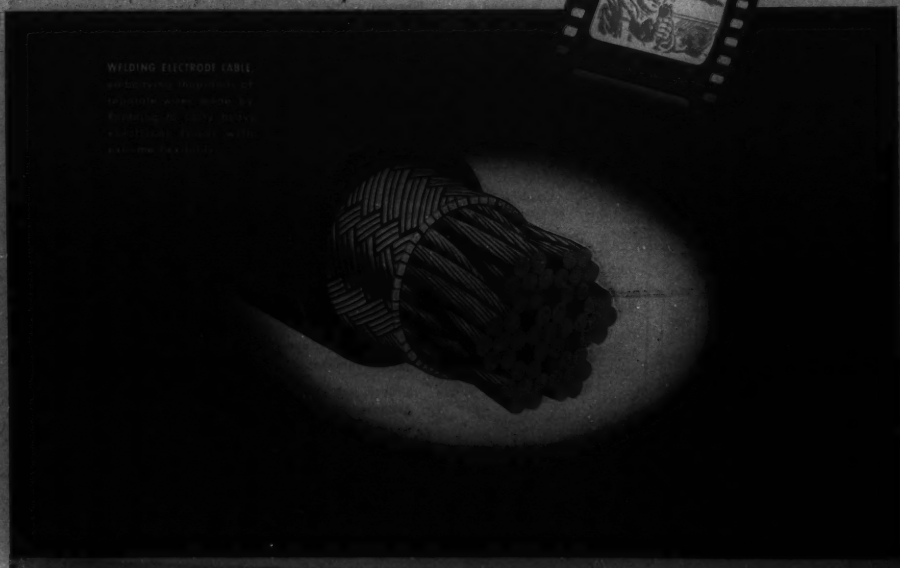
Your Own Trade Mark



The wires and cables you incorporate in your products must be every bit as dependable as the components you produce yourself. To back up our fighters today, and to back up your trade-mark in the peacetime battle of tomorrow, you can count on Roebling Electrical Wires and Cables. The conductors are drawn and stranded and laid with all the skill of years of wire specialization, Metal selection, insulation, finish are supervised with highest integrity.

You can put your trade-mark, without hesitation, on any electrical product you make in which Roebling Wires or Cables carry the loads.

JOHN A. ROEBLING'S SONS COMPANY
TRENTON 2, NEW JERSEY
Branches and Warehouses in Principal Cities



ROEBLING — PACEMAKER IN WIRE PRODUCTS

WIRE ROPE AND STRAND • FITTINGS • AERIAL WIRE ROPE SYSTEMS • COLD ROLLED STRIP • ROUND AND SHAPED WIRE
AIRCORD, SWAGED TERMINALS AND ASSEMBLIES • SUSPENSION BRIDGES AND CABLES • ELECTRICAL WIRES AND CABLES
WIRE CLOTH AND NETTING • HIGH AND LOW CARBON ACID AND BASIC OPEN HEARTH STEELS

The things that REALLY COUNT in station insulators can never be specified

Any number of different individuals can build station insulators and come out with the same size, shape and general appearance; and the insulators, when new, will have comparable physical and electrical properties. These things are covered by standards to which all manufacturers adhere...But there's still a big difference in these insulators--a difference measured by the relative skill of men and refinement of methods--a difference that isn't evident at first, but that shows up years later...In O-B switch and bus insulators, you get these things; a background of the longest and most extensive service records of the entire insulator industry. Thousands of O-B units have passed their 30th year in service. Carrying on in this tradition is a plant equipped and manned to make even a better product today...You can specify certain physical characteristics of a new station insulator, but you can't specify how much a man must know to make it, or how willing he is to apply that knowledge diligently. Nor can you specify how well the insulator will perform in service, or how long. This is all up to manufacturer...O-B gladly stands on its past record in offering station insulators to the electrical industry. Specify them on your next construction.

Industrial Substation Investments Reduced

Two diagrams above show how substations of simplified war-time design are connected to the system. At the top is shown a typical arrangement of a group of three general service substations and three industrial substations; one of which is of war-time design. The industrial substations have a source of power either at the zone center or a general service substation. The lower diagram shows an arrangement with industrial substations supplied by a loop out of a large general service substation. Note simplicity of connections for war-time substation.

Equipment in Minimum-Size Substation

Substation consisting in each case of a single bank of transformers of 1000 kva or more capacity

Equipment in Old-Style Installation:

3 oil circuit breakers, 3-pole, 600-amp, 15-kv, 250,000-kva interrupting capacity
18 S.P.S.T. manually-operated disconnect switches
9 current transformers
3 potential transformers
2 sets of differential balance relays or 6 reverse power relays
3 overload relays for transformer
1 control battery with charging generator
Auxiliary relays, miscellaneous wiring, and other devices
1 bus structure

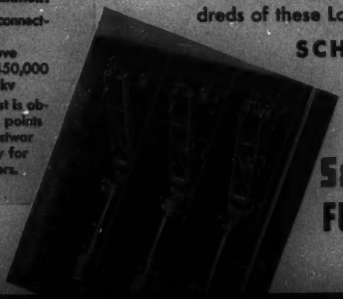
Equipment in New-Type Installation:

1 set of load-break fused disconnecting switches
1 supporting structure for above
3 power fuses, 300,000 to 450,000 kva interrupting capacity, 15 kv

The saving in installation cost is obvious. The above comparison points the way to a probable postwar policy that will be satisfactory for the vast majority of customers.

S&C Load Break Disconnects are equipped with an Interrupter Unit so that the circuit is opened without arcing at the main switch contacts. Short circuit protection is provided by the S&C Type "SM" Power Fuses. The accompanying comparison of equipment (at left) clearly indicates the reduced investment. Our engineers are ready to make recommendations based on experience gained in supplying hundreds of these Load Interrupter Fused Disconnect Switches.

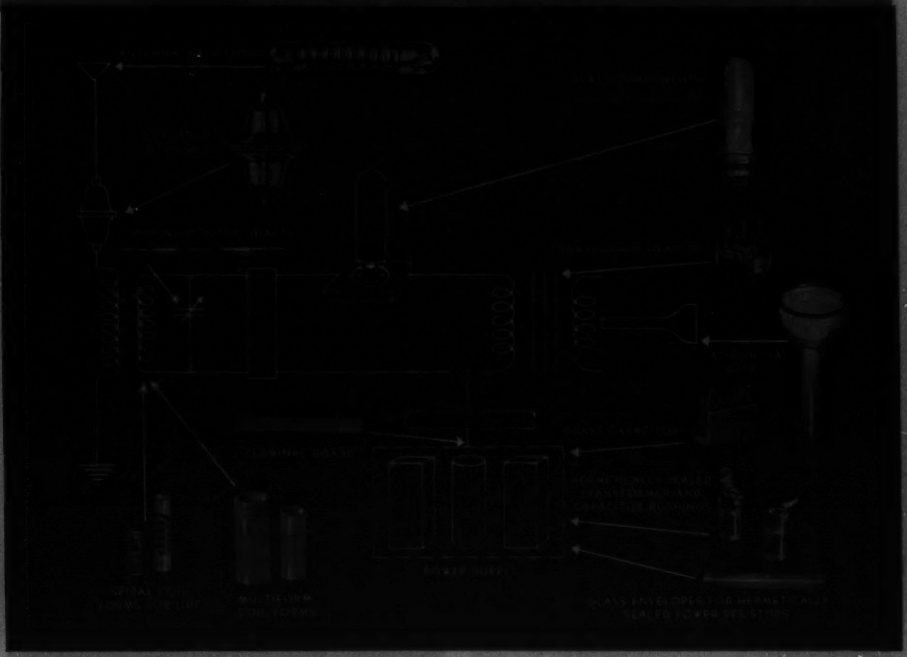
SCHWEITZER & CONRAD, Inc.
4435 RAVENSWOOD AVE. • CHICAGO, 40
Supplied in Canada through Powerlite Devices, Ltd., Toronto, Ont.



Close-up of one bay of cubicle-enclosed Load Interrupter Disconnect Switch and Power Fuse Assembly with door open, showing Load Interrupter Switch and Fuse Combination.

S&C LOAD INTERRUPTER FUSED DISCONNECTS

ARE YOU LETTING GLASS HELP YOU ALL IT CAN?



IT wouldn't be surprising if you aren't familiar with everything glass is doing in electronic equipment today. Progress has been rapid. In the above *"circuit"*, for example, you'll find it on the job in (twelve) vital places. At Corning right now we're making a lot of other electronic glassware that we can't show. After the war we'll tell you all about it.

It's no accident that a major part of the electronic glassware in use got its start at Corning. We've dug in on some tough ones and ferreted out solutions. They told us we couldn't solder metal to glass — they needed glasses with a coefficient of expansion practically equal to that of fused quartz —they needed something to take the place of mica in capacitors — Corning Research found the answers to these and many other electronic problems.

Our 250 glass experts—the men behind "Corning Research"— our facilities and all our knowledge of glass are at your service. Write for a copy of an informative new booklet "There Will Be More Glass Parts in Postwar Electrical Products." Address Electronic Sales Dept. N-10, Bulb and Tubing Division, Corning Glass Works, Corning, N. Y.

CORNING means Research in Glass

Electronic Glassware

CORNING U.S. PAT. OFF. PYREX U.S. PAT. OFF.

"PYREX" and "CORNING" are registered trade-marks of Corning Glass Works

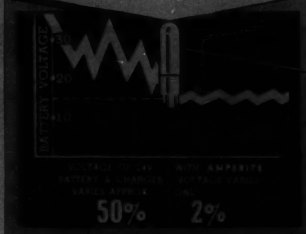
CAPACITRON
Quality
Enters the FLUORESCENT Field!

✓ Check These CAPACITRON Features

1. Designed and built for long and satisfactory life at 85°C.
2. Dried, impregnated, filled and sealed without contact by human hands . . . thus avoiding all possibility of body acid contamination.
3. Less than 2% power factor at operating voltage and temperature.
4. Condensers are mechanically sealed and do not depend on solder . . . eliminating the possibility of all leaks at high temperatures caused by "solder-blow".
5. Available for acceptance to UL and ETL approved ballasts.

The CAPACITRON *Company*
318 West Schiller St. Chicago 10, Illinois

ENGINEERS: Here's the BIG POINT about AMPERITE REGULATORS



Features:

1. Amperites cut battery voltage fluctuation from approximately 50% to 2%.
2. Hermetically sealed—not affected by altitude, ambient temperature, humidity.
3. Compact . . . light . . . and inexpensive.

DELAY RELAYS: For delays from 1 to 100 seconds. Hermetically sealed. Unaffected by altitude . . . Send for catalogue sheet.

HELP! Let our engineers help you solve Current and Voltage Problems. Submit your reliable data in detail. Samples sent for your tests.

AMPERITE CO., 561 Broadway, New York 12, N. Y.
In Canada: Atlas Radio Corp., Ltd., 560 King St., W., Toronto

HYVOL *Oil* CAPACITORS

6000 to 50,000 Volts

● **Aerovox Type 20 oil capacitors are available in ratings from 6000 to 50,000 volts D.C.W. (single section) and in 25,000 volts D.C.W. (12,500–12,500 volts) dual units, for voltage-doubler circuits. Now used for critical military purposes, these extra-heavy-duty Type 20 capacitors will be available for power factor and other industrial applications after victory. Write for literature.**

Hermetically sealed. Welded steel casing. High-voltage insulator terminals.

Hyvol-impregnated and filled. This dielectric maintains effective capacitance over widest temperature range.

Single-section units of 30 KV or less normally supplied with capacitor section insulated from ground. Higher voltage units with grounded case.

AEROVOX *Capacitors*
INDIVIDUALLY TESTED

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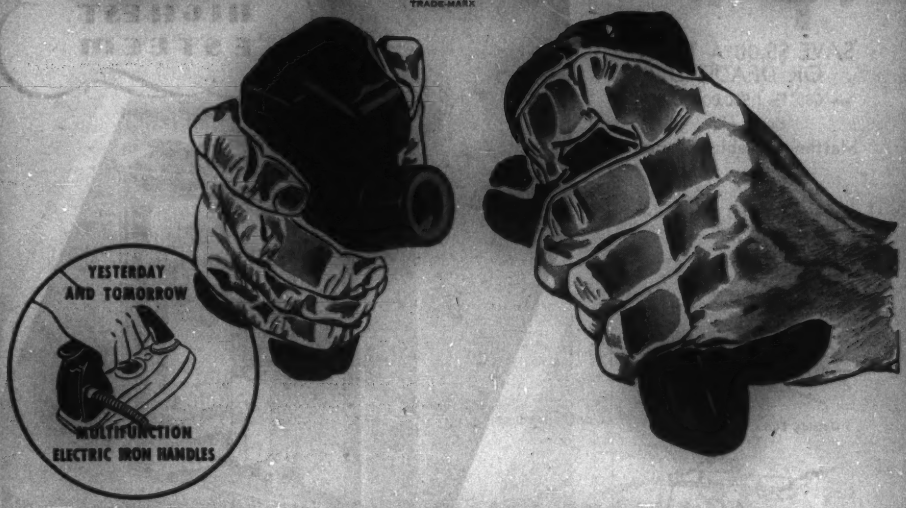

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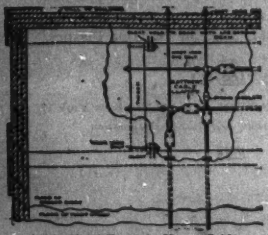

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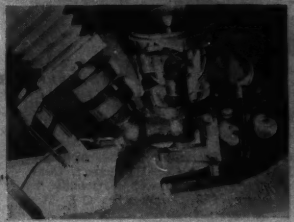

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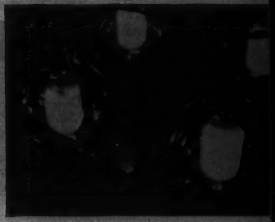

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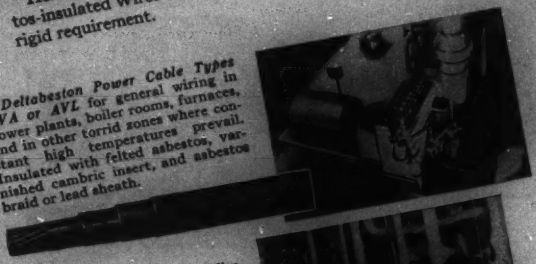

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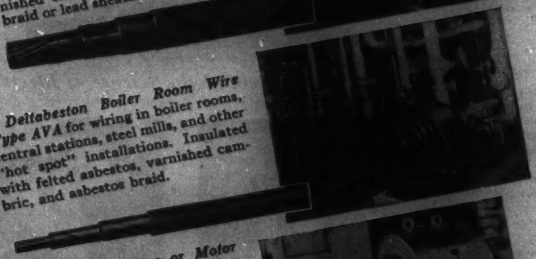

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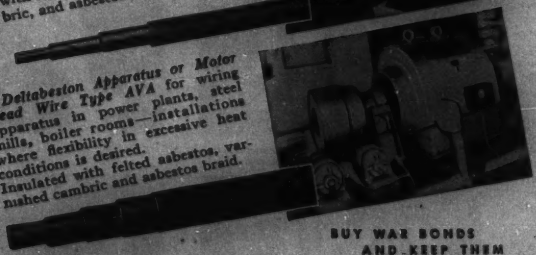

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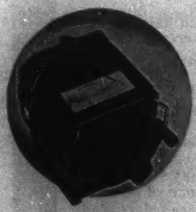

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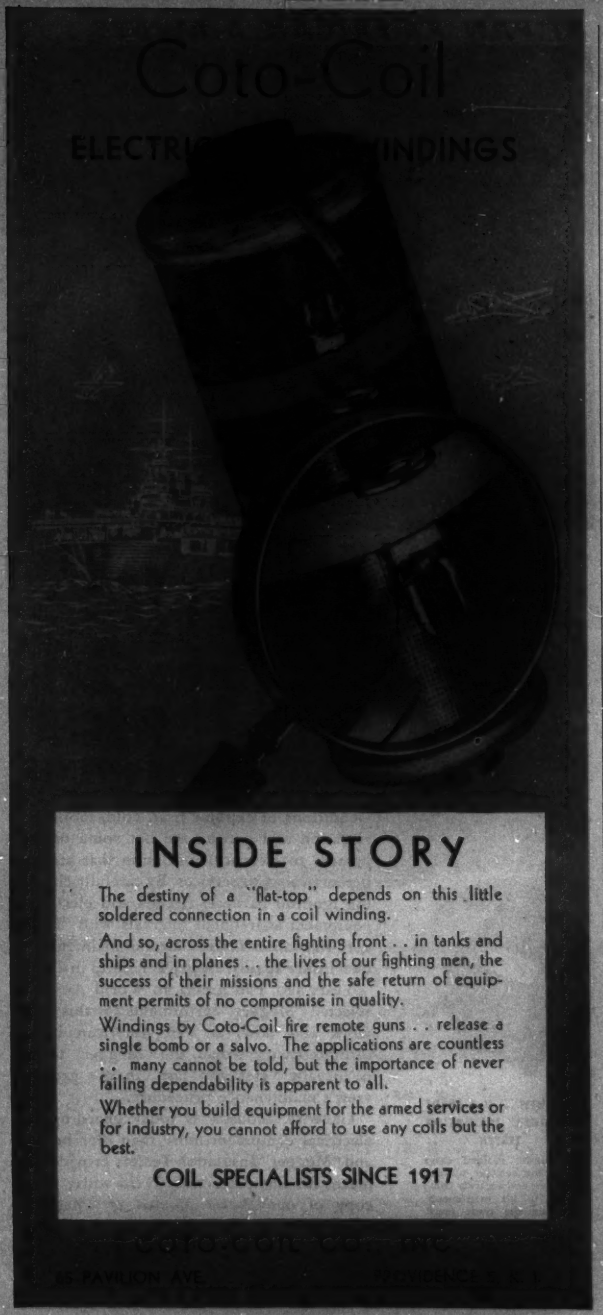

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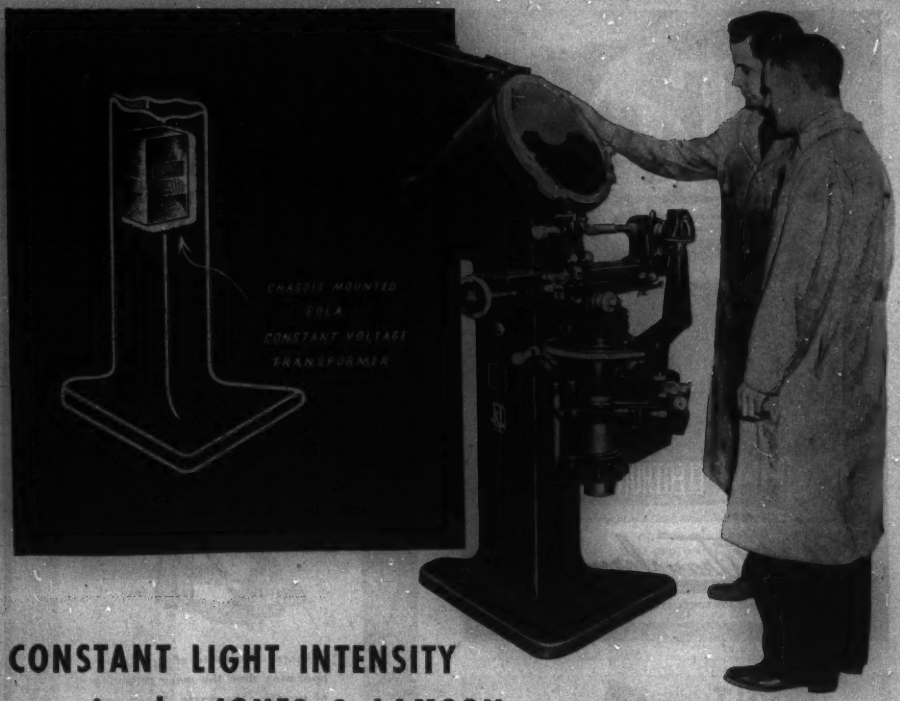

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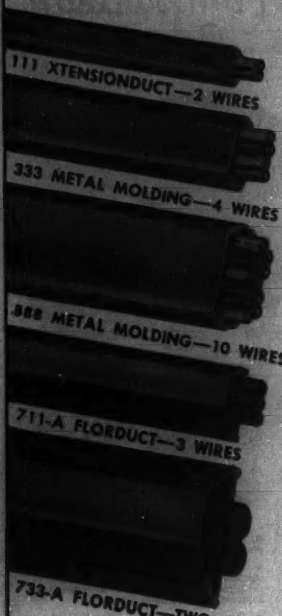

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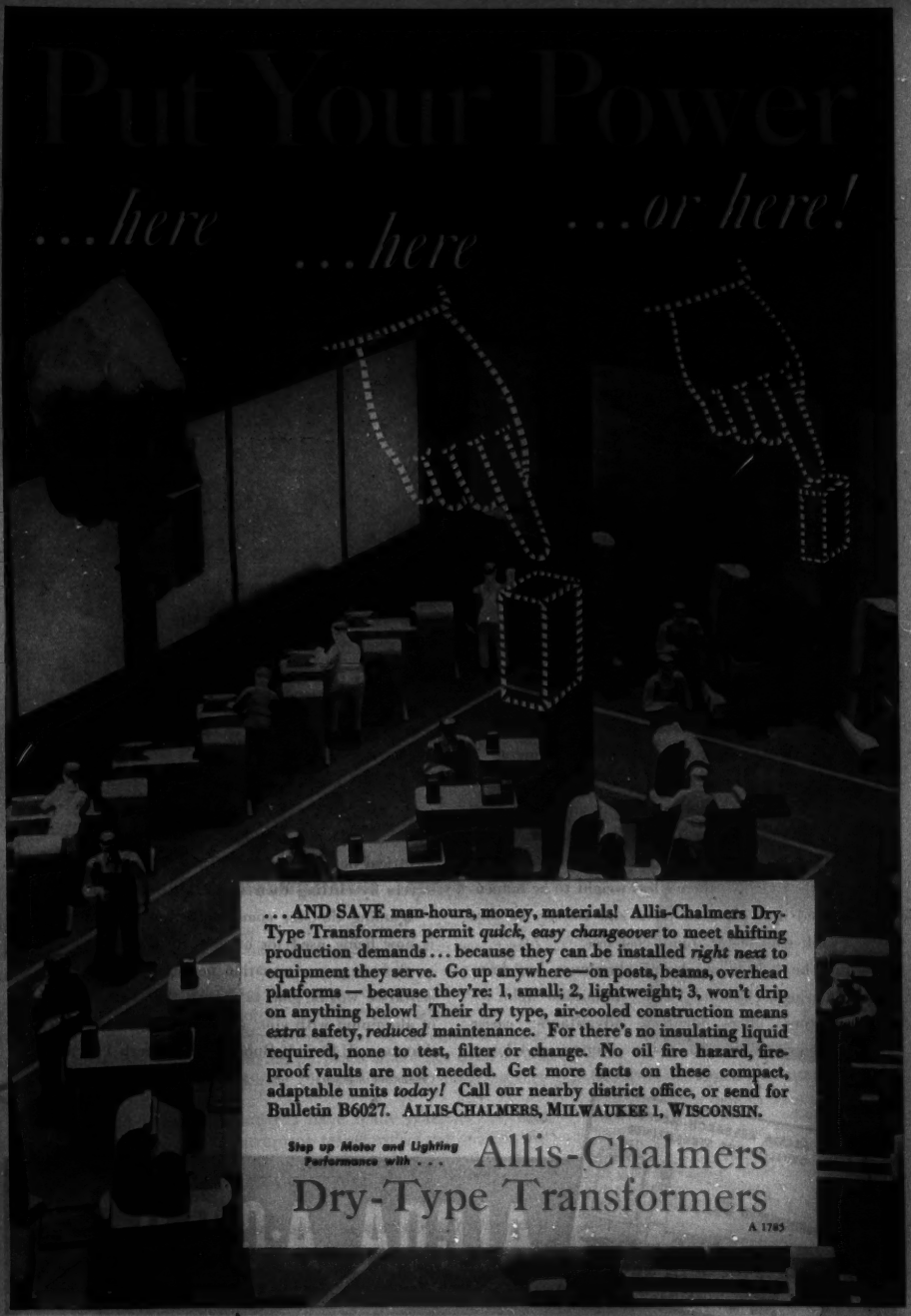

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Answer:

ASA Burden	B-0.1	B-0.2	B-0.5	B-2
ASA Accuracy Class	0.3	0.3	0.3	0.3

This means that with standard ASA burdens, the ratio correction factor and the transformer correction factor will be within the limits of the ASA accuracy class 0.3.

NEMA Burden	X	Y	Z
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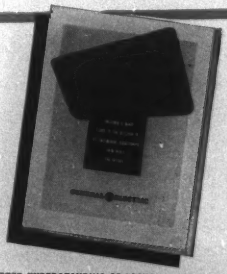

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